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BACKGROUND DOCUMENT FOR AN ADVANCED PERSONAL LOAD CARRIAGE SYSTEM FOR THE CANADIAN FORCES

FINAL

BACKGROUND DOCUMENT FOR ADVANCED PERSONAL LOAD CARRIAGE SYSTEM FOR THE CANADIAN FORCES

Submitted to

Defen~~s~~ce and Civil Institute ~~for~~ of Environmental Medicine

from

Ergonomics Research Group
Queen's University

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1.0 EXECUTIVE SUMMARY

As part of the research for the Advanced Personal Load Carriage System (APLCS) for the Canadian military, the Ergonomics Research Group (ERG) at Queen's University has performed an extensive review of current load carriage systems and load carriage literature.

A background report on the evolution and current state of load carriage equipment was prepared for ERG. Civilian expert trekkers responded to interviews covering many design features and ergonomic preferences for current load carriage systems. They reviewed the three military and one commercial pack that ERG possesses.

Military load carriage equipment from Canada and two foreign countries has been examined and evaluated by our team of scientists and load carriage experts. Canadian military personnel have provided feedback through questionnaires and interviews on the strengths and weaknesses of various design elements. Additional information was solicited on load carriage limits, typical tasks and operating conditions. In some cases, there are clear deficiencies in some design elements. However, in many instances the success of a particular configuration is individual and/or task and/or environment specific. One of the main benefits of this review has been a better understanding of the interplay amongst these factors.

Scientific and popular literature on load carriage design elements and performance ratings has been summarized in this report. Many studies have been performed to assess the effects of load carriage on humans. Factors studied included total load, load distribution, and various load carriage systems. Conditions range from forced marches of several days to balance, treadmill or circuit tests in the laboratory. Formal assessment methods are mostly based on physiological or biomechanical measurements or ratings of perceived exertion.

The principal conclusions of the scientific literature review are that biomechanical measures and subject perceptions are good indicators of certain design variations in load carriage systems, but have not been developed to full advantage. Generally, physiological measures are not sensitive enough to reflect subtle changes in configuration, although they provide very useful information on the effects of total load and environmental conditions. Also, the relationship between user perceived stress under load and quantitative measurements is not very well developed. That is, a quantifiable, repeatable measure of the ergonomic merit of a design is still an open area of research, which ERG is undertaking in this project.

2.0 INTRODUCTION

The Defence and Civil Institute of Environmental Medicine (DCIEM) has been charged with the task of research and development of Land Forces Protective Clothing and Equipment for the Canadian Forces. This project involves an Improved Environmental Clothing System (IECS) for all CF personnel, Integrated Protective Clothing and Equipment (IPCE) for combat arms and Enhanced Integrated Protective Clothing and Equipment (EIPCE) for assault troops. DCIEM is in contact with parallel developments in the United States, and the United Kingdom, and is prepared to support NATO's "soldier modernization plan".

One facet of the IPCE master plan is the assessment and development of Advanced Personal Load Carriage System (APLCS). The current CF load carriage system is not deemed adequate to carry all of the high technology items in combat conditions (i.e. portable power source, computer, video camera, etc.). The Ergonomics Research Group (ERG) at Queen's University has been tasked to initiate the APLCS component of the IPCE project. The first year of this study includes a thorough review of literature and current load carrying equipment, culminating in this interim report. The concurrent development, set-up and application of laboratory mechanical and performance testing systems by ERG will be described in the first year's final report.

A load carriage system (LCS) must not be developed in isolation, particularly given the demanding duties and diverse conditions encountered by Canadian military personnel. The ultimate effectiveness of the LCS must be measured in relation to its bearer, its contents, and the tasks and environments to which it is subjected. This report will touch upon all of these factors, though the focus is on the physical effects of the load carriage system on the soldier. The report comprises two main sections: an evaluation of current civilian and military load carriage systems; and a review of the literature pertaining to the ergonomic aspects of load carriage. By presenting the material in this order, the reader gains an appreciation of the features, uses, strengths and weaknesses of a variety of current designs. This foundation permits a greater appreciation of the subsequent review of detailed scientific studies showing the physiological, biomechanical and subjective responses to various load carriage configurations and conditions.

3.0 REVIEW OF CURRENT LOAD CARRIAGE SYSTEMS

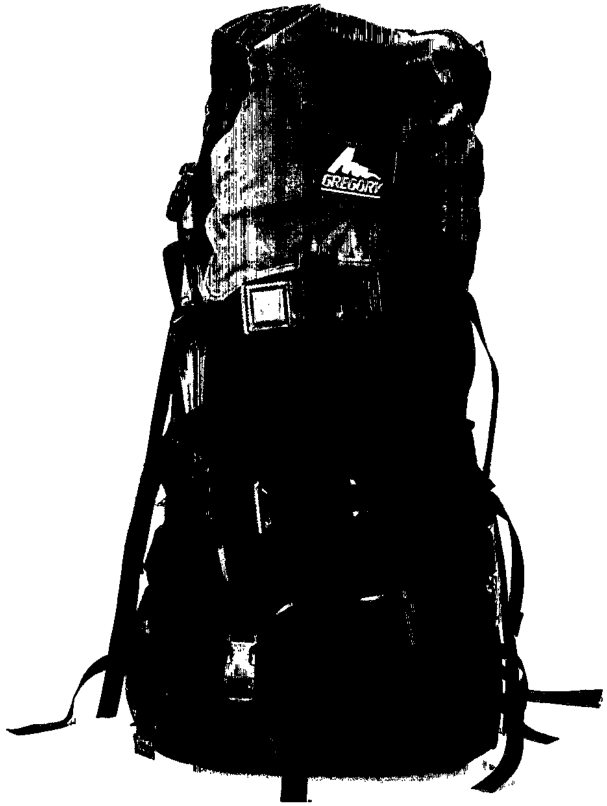
Personal load carriage systems have a long history in both military and non-military contexts. A review of current and historical packs provides a wealth of information on the advantages and disadvantages of numerous configurations and design options. Information has been gathered using a variety of sources and methods. Actual backpacks, and other load carriage components such as webbing and load carriage vests have been examined. Opinions have been solicited from experienced military (Appendices 7.1 and 7.2) and civilian (Appendix 7.3) users via interviews, questionnaires and presentations. Military reports and documents have been perused, as well as articles from the general literature. This feedback on features and uses also provides insight into the development process as packs have improved over time, as well as suggestions for future modifications.

Civilian systems are discussed first, to lay a generic framework for the review of the more specialized military load carriage systems. A summary of current load carriage systems presented in section 3.5 also touches on certain protocols to be followed in developing and testing new systems.

3.1 *Civilian Load Carriage Systems*

Civilian packs have many elements which are or could be used in a military context. The technological edge in improvements in suspension systems, closures, materials, and adjustability has often been driven by the commercial pack manufacturers. Two models are shown in Figure 3.1. A report reviewing commercial load carriage systems, from early times to the present was prepared by Dr. James Raffan of Queen's University for the Ergonomics Research Group and is included in Appendix 7.4 of this report.

However, the differences between military and civilian load carriage requirements are generally greater than their similarities. Military kit comprises items common to any expedition, such as clothing, sleeping gear, and eating equipment. Weapons, ammunition and specialized items such as radios however often dominate the load in terms of weight and accessibility. The uses (fording rivers, transporting 50 kg, jetissoning the pack) and abuses (tossing packs out trucks or parachuting with them) during military manoeuvres bear little



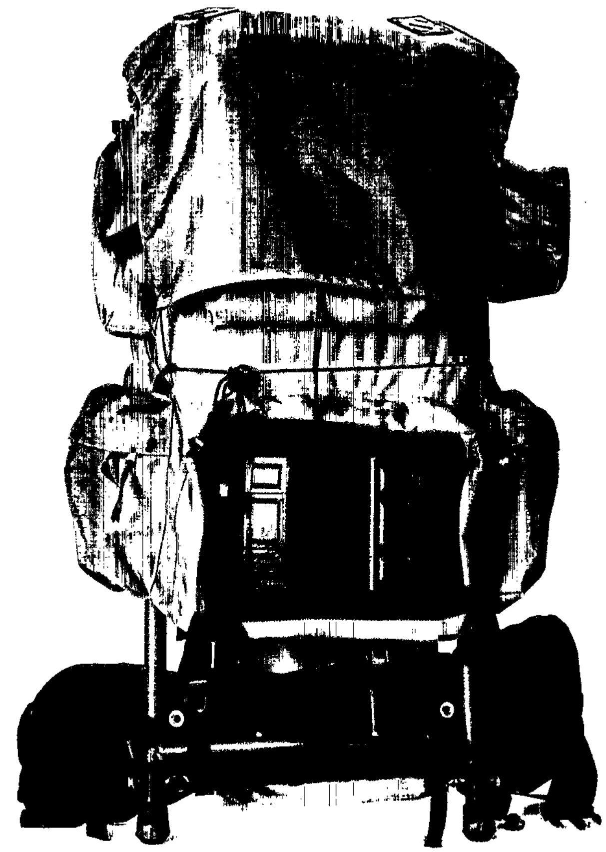


Figure 3.1 Gregory "Dru" Pack

Camptrails Pack

resemblance to commercial applications. Nevertheless, many elements of commercial load carriage systems could be transferred to military systems in their original form (such as Fastex buckles) or as ruggedized versions (i.e. more durable models for heavy field use).

A single commercial pack is reviewed in detail in the following section, although other makes were examined informally in a variety of settings. Comments on other commercial packs are provided in Appendix 7.4.

3.1.1 Design Features. The design features of the internal-frame "Dru" model made by Gregory Mountain Products of California were reviewed (Figure 3.2). This pack is a mid-sized pack designed for trips approximating five days. Its capacity, as rated by the manufacturer, is 85.2 L and it weighs 15.6 kg unloaded. It is approximately 81 cm high by 38 cm wide by 20 cm thick when fully loaded.

a) Frame:

- internal frame sheet made from high density polyethylene, with 2 carbon fibre parallel stays which are bolted on at the bottom and sit in pockets at the top
- occipital notch in frame for head clearance

b) Padding:

- patented Flo-Form padded back with contouring grooves to allow air circulation
- lumbar pad is large, smooth and about 4 cm thick
- shoulder harness is about 6.5 cm wide and padded at about 1.9 cm thickness
- waistbelt consists of 4 sections of padding (not one complete piece) about 3.8 cm in thickness

c) Adjustability:

- shoulder harness can be raised or lowered on the framesheet to three locations which are about 2.5 cm apart to allow for different torso lengths
- shoulder harnesses are available in three sizes
- lower shoulder strap adjustment changes length and tension of shoulder strap
- load-lifter straps stabilize the upper part of the pack: loosen to shift weight to the hips; tighten to put more weight on shoulders
- sternum strap can be adjusted up or down by sliding

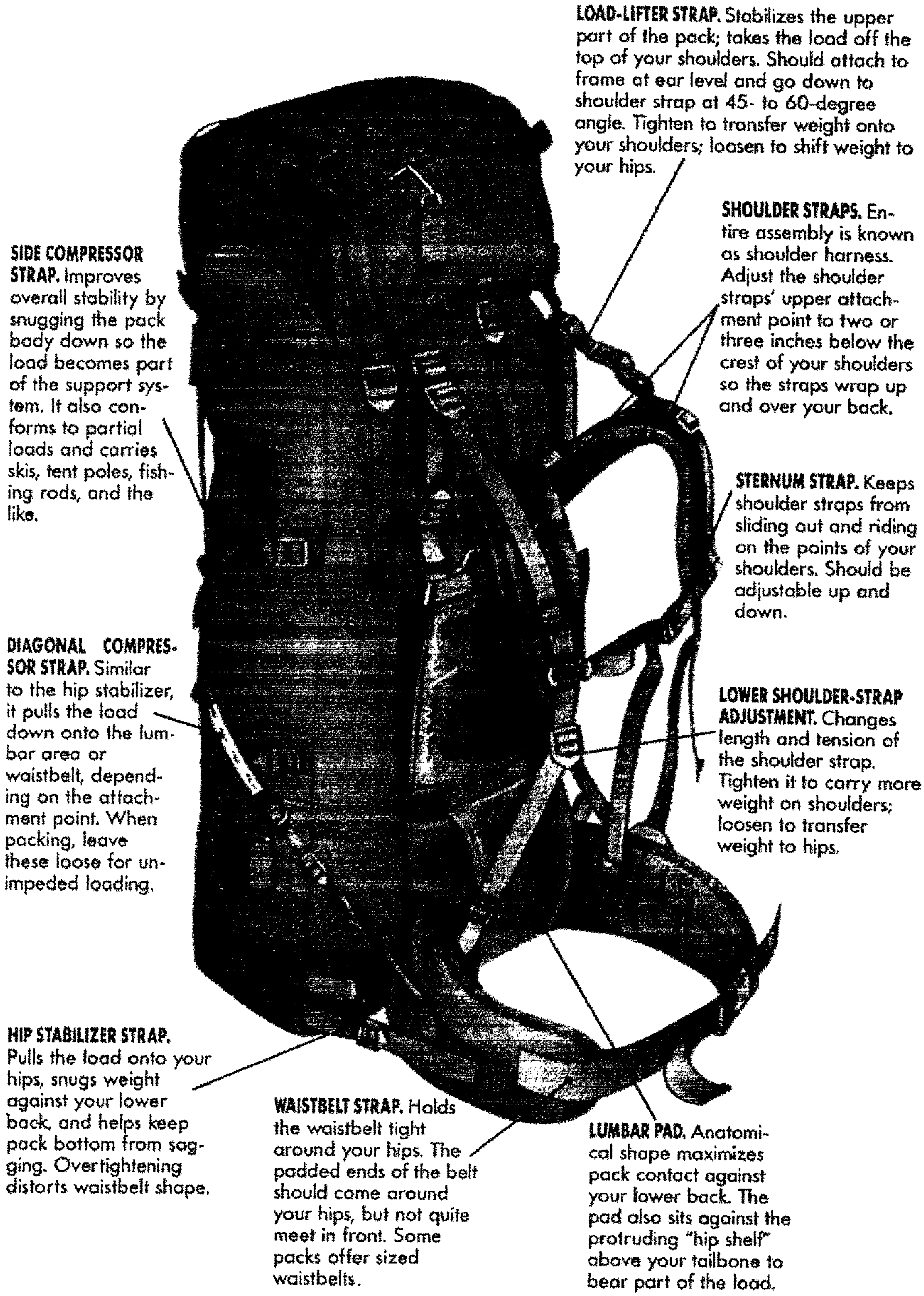


Figure 3.2 Gregory internal frame "Dru" pack

c) **Adjustability (cont'd):**

- hip stabilizer strap pulls the load in closer to the hips, snugs weight against the lower back, keeps pack bottom from sagging
- waistbelt strap holds the waistbelt tight around the hips
- waistbelt comes in three sizes
- sternum strap keeps the shoulder straps from sliding outward; one side of strap is elastic; buckles together

d) **Pockets:**

- one large inside compartment with 2 cloth dividers on each side, drawstring closure, with additional rain-cover flap with drawstring (spindrift collar)
- smaller pocket on bottom of pack (large enough for sleeping bag), double zipper closure, waterproof cloth overlap
- two side pockets on the bottom of pack made of nylon webbing (see-through)
- top pocket features main compartment, map compartment, snap key hook, double zipper closures, (pocket detaches completely from main pack)

e) **Attachment Points:**

- four square, flat, plastic lashing points on the back of pack
- four buckles where straps can be attached on back of pack
- two large loops on the left and right sides on back of pack
- two long straps with buckles attach at bottom of pack and just above lower compartment
- two long straps with buckles attach at top of lower compartment and on the top pocket
- four buckles on each side of the pack, two up and two down
- two small plastic D-shape loops on the front of shoulder harness

f) **Compression Straps:**

- two on each side which travel on a slight angle from their attachment on the back of the pack through a loop on the front of the pack and back again on an angle to buckle

g) **Quick Release:**

- not available

h) **Carrying Handles:**
- one loop carrying handle on top of pack between the load-lifter straps

i) **Extras**
- made of durable Cordura Nylon
- rain cover is available
- compression stuff sack for sleeping bag

3.1.2 Field Evaluation of Packs. From the published literature on civilian backpacks, it would appear that very little quantitative research is available. The primary evaluation strategy appears to be focus groups which pilot test new product lines in the field. Perlman, in Backpacker Magazine (1987) listed the names of nine companies that designed and manufactured backpacks in the United States. Along with descriptions of the various packs and their features, the author made reference to the fact that some companies had based current redesign on tests and evaluations done and reported in the previous year's Backpacker equipment review. This is a valuable approach, however it may fail to capture individual differences, and to accommodate all body types. It would appear that load carriage equipment could be improved and adapted to the individual more effectively and efficiently, if a quantitative approach could also be developed.

Parker (1990) describes some performance trials for large packs (98 L). Five full-time guides from the American Alpine Institute, with more than 70 cumulative years of experience climbing the world's major mountain ranges, were asked to test nine of the largest top-loading internal-frame packs. The exact amount of time taken to evaluate the packs is not given. However, the author writes that the packs were used on 3- to 14-day trips, out on trails and up and down mountains including Mount Baker, the Canadian Rockies and rock climbs in the Pacific Northwest. The testers then completed standardized field evaluation forms which included ratings on specific points and general comments as well. Categories of evaluation included:

1. **Ease of suspension adjustment** (testers' sizes ranged from 193 cm & 88.5 kg to 162.5 cm & 57 kg). Some packs come in different sizes as well as having highly adjustable suspensions and interchangeable shoulder straps, and waist belts.

2. **Comfort.** A good pack reduces strain, does not cause friction on the shoulders and hips, and transfers the load weight from the shoulders to the waist when it is required.

3. **Loading.** This refers to how easily the load can be filled and then removed. Guides generally prefer one or two large compartments rather than several small ones. Other factors are access into the load through zippered openings, and lashing straps for exterior add-ons, that are separate from compression straps.

4. **Load Control.** This rating reflects how well the pack moves with the carrier, i.e. does the pack affect the movement or balance of the wearer, or does it hug the contour of the body, and move with you.

5. **Durability.** This assessed the fabric, reinforcement of wear points, workmanship, quality of stitching and tolerances of fasteners and buckles.

6. **Versatility.** The ability to reduce pack volume with compression straps, and the add-on pockets/pouches defined this category.

A slightly different approach is taken by Townsend (1991) who emphasized that although packs often come with adjustable parts, the pack carrier often does not know how to make the correct adjustments, for his/her body build. Fitting instructions are sometimes too brief or are difficult to decipher.

Basically, to properly fit a pack the following steps should be taken:

1. Load the pack with equipment or sandbags (15 kg) and loosen off all the adjustment straps.

2. Put the pack on and do up the hipbelt so that it is covering the hips (not sitting on top of the hip bone). Tighten the belt comfortably. The padded part extends in front of the hips. Tighten the hip stabilizer to pull the load in around the hips for stability.

3. Now adjust the back length (method depends on the pack design), so that the shoulder straps sit comfortably. The point of attachment of the strap to the bag should be about 5-7 cm below the top of shoulders. The load-lifter straps, which go from the shoulder harness to the bag, should be at about a 45% angle. Tighten load- lifters to transfer weight onto the shoulders; and loosen to shift weight to the hips.

4. Tighten the side compression straps to snug the pack into the body and consolidate the load.

CRITERIA FOR EVALUATING CIVILIAN LOAD CARRIAGE SYSTEMS

Feature	Components	Comments/Critical points
Physical Measurements of the Pack	Weight	the unloaded pack/frame
	Capacity	volume of the pack, can this be altered by add-on pockets
	Size	available sizes - s,m,l
	Shape/Dimensions	length, width, height - head/arm clearance for awkward manoeuvres?
Loading	Ease of Filling/Removing	how does it load - top or panel how easy is it to access the load?
	Organizing	separating gear - # of pockets, # of compartments, dividers
	Lashing/Loops/Rings	straps, loops, rings for adding equipment on the outside - secure
	Fasteners/Zippers	are buckles/fasteners easy to use width/length of zippers
Adjustment of Suspension	Shoulder Harness (fit and adjust)	to what extent can it fit a wide range of body types, are there different sizes? how easy is adjustment?
	Waistbelt (fit and adjust)	as above for shoulder harness, are tools or manual required?
	Sternum Strap	for comfort should slide up/down, can it handle extra clothing layers
	Adjust Load Position (Load-lifters) (Hip-stabilizer)	can load be pulled in tight to the shoulders or moved out again, load pulled into hips and lower back
	Compression Straps	the load should not be loose/moving ability to compress not-full load

CRITERIA FOR EVALUATING CIVILIAN LOAD CARRIAGE SYSTEMS (cont'd)

Feature	Components	Comments/Critical points
Durability	Harness System	reinforced stress points at waistbelt, shoulder straps & suspension
	Fabric	weight of fabric used; abrasion, rot, resistant; reinforced at wear-points
	Quality of the Stitching	double or triple-sewn, with additional taped seams
	Tolerances of Fasteners, Buckles, Straps, Zippers	heavy-duty, cold resistant, superior strength
	Waterproofing	what is waterproofed i.e. bottom, top quality of proofing
	Framesheet (internal) Frame (external)	composition - plastic,aluminum, magnesium, shape, tolerances welds, joints
	Stays	flexible but strong, carbon-fibre or aluminum, how are they held in place (bolt,rivet,pocket)
Comfort of Suspension System	Shoulder Straps	width, thickness, density and contour of padding, "soft" or "hard"
	Sternum Strap	is the position adjustable, should hold shoulder straps in place
	Lumbar Pad	size, shape, thickness, what kind of fabric, breathable moulded quality of foam, channels for air circulation
	Hip Belt and Pads	size, shape, thickness, what kind of fabric, breathable moulded quality of foam
	Framesheet	adds support, does contour fit curve of the body, occipital notch
	Headroom	can accommodate all head positions, can a hat (helmet) be worn?
Load Control	Freedom of movement	arms, trunk, head move without restrictions
	Stability and Balance	does pack stay with you

Jenkins (1992) placed emphasis, when discussing design, on the function of the pack. He began by describing the design and functions of the external-frame pack and the internal-frame pack. The external-frame pack, was portrayed as the tractor trailer of backpacking. Advantages included: ability to carry a heavy, awkward load; air circulation occurs between the load and carrier's back; multiple pockets for gear organization. Disadvantages were: mobility problems in the woods, usually because of the frame; balance problems due to high centre of gravity; and the height of the frame impeding the tilting of the head. On the other hand the internal-frame pack was described as the jeep of backpacking, designed for active travel. Advantages listed were: pack is strapped close to the body for greater stability and load control; the load sits somewhat lower which aids stability as well; suspension parts can be custom fit; and the packs tend to be more streamlined which offers better arm clearance. Disadvantages: pack is close to the body so little air circulation. Jenkins warned that rated cargo capacities of backpacks (in cubic inches, U.S. and litres, CAN) are not always reliable for comparisons. For example, the gear that completely overstuffs a large capacity internal (90 L), may fit comfortably into a smaller capacity (50 L) external pack, because of the difference in design, i.e. the sleeping bag could be strapped onto the external's framework.

Getchell and Howe (1994) made the point that backpacking does not have to be an exercise in sore-shouldered masochism, even when carrying a load that is large enough for an extended trip where items such as food, cold-weather clothes, camping equipment and the like are required. They emphasized fit as being the number one criterion for choosing a pack because it directly relates to comfort. Descriptions of the external-frame pack concurred with Jenkins (1982). Favourable to the external is that it offers good ventilation against the back, allows for a relatively straight-up stance, has heavy load-hauling capacity and top loading and panel loading are available. The drawback is that the external is more likely to be poorly balanced, often causing the wearer to sway. The internal-frame design incorporates the load weight transfer elements into the pack bag itself, by using flexible stays of aluminum or graphite to transfer weight onto a padded, stiffened hipbelt. The flexible plastic frame-sheet adds additional support (Getchell and Howe, 1994).

Even though the evaluations and testing of backpacks has been done in the field by expert focus groups, the actual format of the testing (procedures, controls, etc.) has not always been described. The categories of evaluation are often described in broad terms such as "stability" or "volume" without precise definitions. Howe (1994) was one of the first authors reviewed to describe the methods used for field testing and evaluating. Eight backpacks were loaded with an average of 16 kg. The test crew consisted of two women and three men, and there was a wide range of body types and sizes (160 cm petite to 196 cm long torso). They hiked and climbed for two days over a varied countryside described as flat slickrock, boulder fields, narrow-seam canyons and cliff scrambles. The group stopped four times a day to fill out evaluation forms, switch packs and loads, and adjust the harnesses. Testers rated 20 parameters in all, on a scale from one to five. One meant poor and five was excellent. The 20 scales were combined and averaged into seven headings: loading, harness, comfort adjustment, load, quality control, value, overall and hi/low points. Although the two-day format did not allow for evaluating durability, they were able to rate ease of loading, simplicity of adjustment, overall comfort, and stability of the load.

3.2 *Canadian Military Load Carriage*

The Canadian load carriage system consists primarily of the pattern webbing, a harness/belt combination to which kit can be attached, and an external frame rucksack (Figure 3.3). Each of these is described and assessed in detail below. However, variations on this standard issue are encountered because some soldiers modify their system to overcome deficiencies (such as combining the current pack with its predecessor's frame). Furthermore, ongoing innovations have lead to the current development and testing of a better rucksack and load carriage vest for the Canadian military.

3.2.1 Design Features of the Canadian 1982 Pattern Webbing and Rucksack. The following is a description of the 1982 Pattern Webbing and Rucksack. Each design feature of these load carriage systems is described and diagrams are provided from the 1982 Pattern Webbing Users Field Manual, 1992 DND Canada.

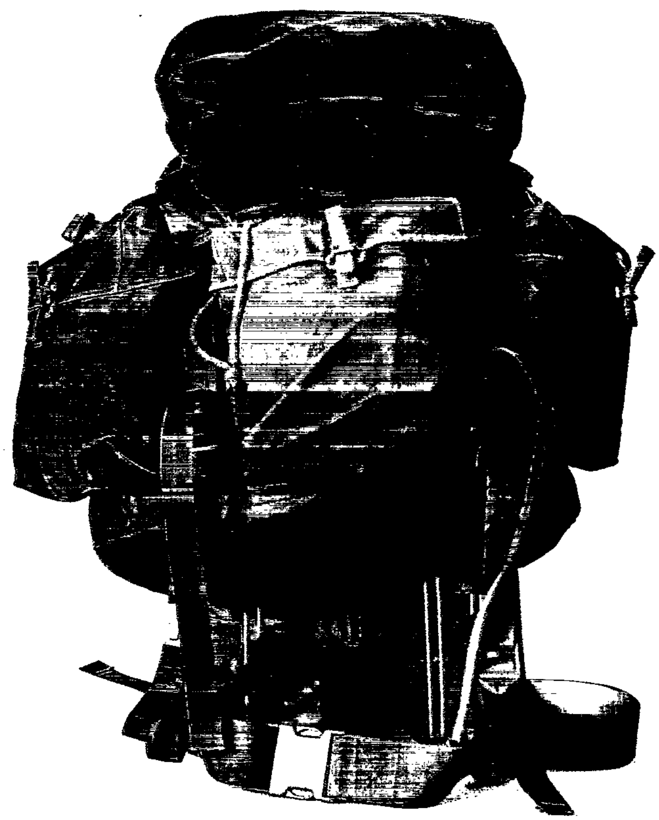


Figure 3.3 Current Canadian Pack

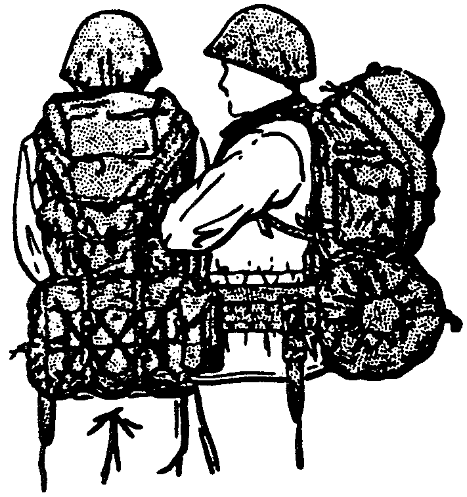


Figure 3.4 1982 Model Webbing and Rucksack

RUCKSACK

a) **Frame:**

- external metal frame which is narrower at the bottom and rounded in a bowl-like fashion at the top (figure 3.5)

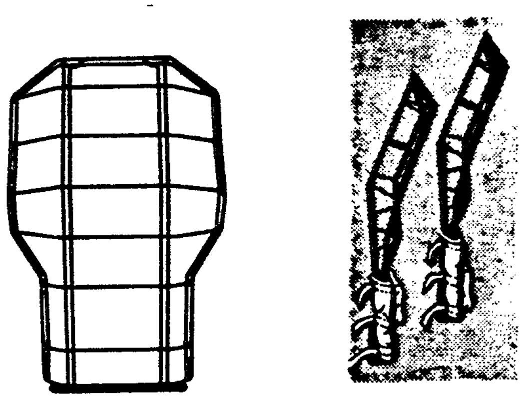


Figure 3.5 Metal frame

b) Padding:

- padded shoulder straps are attached to a padded harness which attaches to the frame in different places to accommodate various body shapes and sizes
- lumbar pad near bottom of frame to cushion the back

c) Adjustability:

- shoulder straps can be adjusted to make the load closer to the body and the straps tighter on the shoulders
- waist belt (unpadded) attaches to the frame and closes with a large Fastex buckle (figure 3.6); there are two positions where the waist belt can be attached to the frame to accommodate people of different heights; the tightness of the waist belt around the waist can be adjusted from only one side of the Fastex buckle.
- lumbar pad attaches to the bottom of the pack in one of two positions to accommodate personnel with long or short bodies torsoes
- two load stabilizing straps (one on each shoulder) connect the top of the pack to the shoulder straps. When load stabilizer straps are pulled the centre of gravity of the ruck is pulled forward closer to the centre of gravity of the person wearing the pack.
- there is no sternum strap but there are two D-rings on the shoulder straps that can be tied with a piece of string as a makeshift sternum strap.

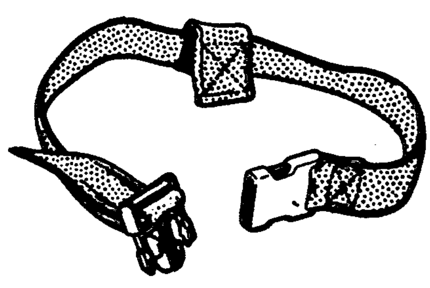


Figure 3.6: Waist belt

d) Pockets

- the bag portion of the rucksack is attached to the frame with a rope that runs through the frame and eyelets on the bag (figure 3.7)
- there is one large compartment on the interior of the bag and a smaller compartment, designed to accommodate a PRC 77 radio; the large compartment closes with a drawstring; there is a zipper on the top of the bag close to the frame which provides access to the inside radio pouch (figure 3.8)
- on the exterior of the rucksack there are three pockets of equal size, which close by inserting a plastic ring on a flap covering the top of the pocket over a plastic ring on the main compartment of the pocket. A hard rope like fastener is then inserted through the ring attached to the main body of the pocket (figure 3.9)
- there is a pocket on the outside lid of the rucksack that is accessible from the top of the bag near the top of the frame. It is closed with a two way zipper.
- there is a pocket on the inside of the lid which is closed by a two way zipper. The lid closes onto the main body of the rucksack with two straps and two plastic clips.
- the valise is the bag which stores the sleeping bag. It closes with a drawstring that is outside a material flap. The valise has a criss-crossed string on one side that compresses the contents (figure 3.4)

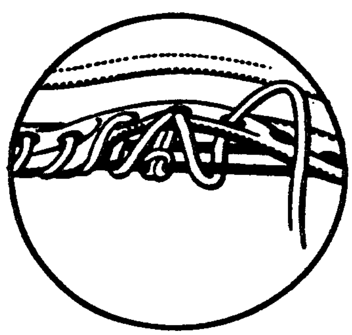


Figure 3.7: Detail of attaching bag to frame

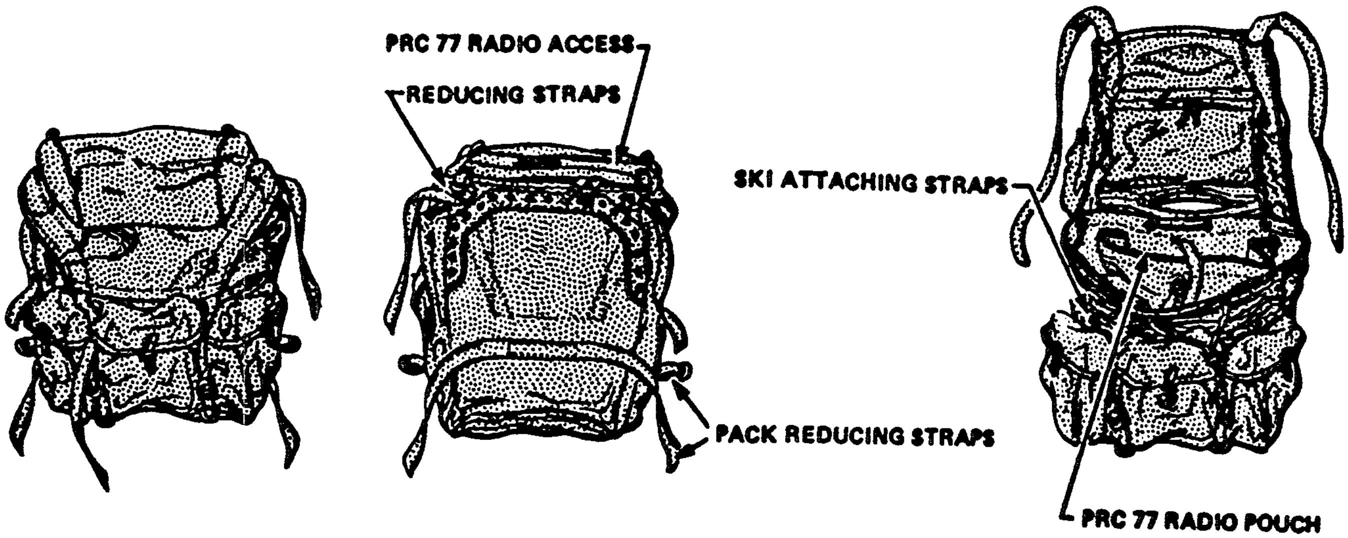


Figure 3.8: Radio pouch, reducing straps, and ski attachment straps

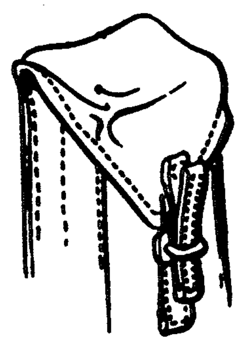


Figure 3.9: Pocket and component closures

e) **Attachment points:**

- ski attachments: skis can be inserted into slots behind the two side pockets and secured with ski attachment straps (figure 3.8)

f) **Compression Straps:**

- four pack reducing straps, one on each side and two on the top (figure 3.8)
- straps go around the valise and through two plastic loops on the bottom of the bag and through the bottom of the frame (figure 3.10); the straps have plastic clips to adjust the tension and compress the valise

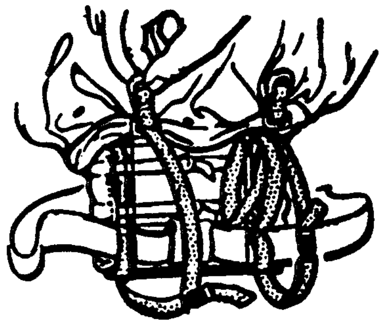


Figure 3.10: Sleeping bag attachment

g) **Quick Release Mechanism:**

- consists of a cord on each shoulder strap that releases the shoulder strap that it is attached to (figure 3.11)

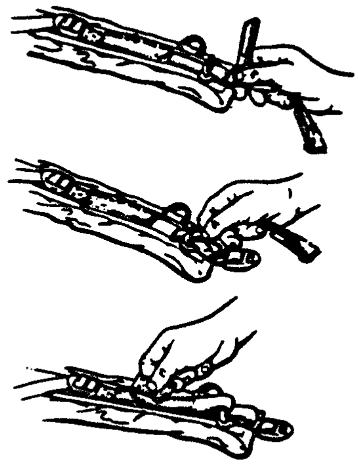


Figure 3.11: Quick Release Mechanism

WEBBING

The webbing consists of a utility belt and a yoke. The two are attached together with straps that attach through plastic buckles. When the webbing and the rucksack are worn together the shoulder straps of the rucksack go over the straps of the webbing (figure 3.12).

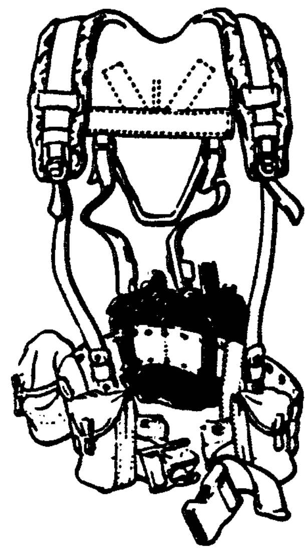


Figure 3.12: 1982 Pattern Webbing

Utility Belt The utility belt is used to carry fighting order components and is issued in three sizes to accommodate people of different sizes. The utility belt has a row of grommets along the top and the bottom. The components have a plastic support equipped with hooks on the top and bottom. Then the plastic support is bent slightly to insert the hooks into the grommets on the utility belt. Velcro flaps on the components then wrap around the support and the utility belt (figure 3.13).

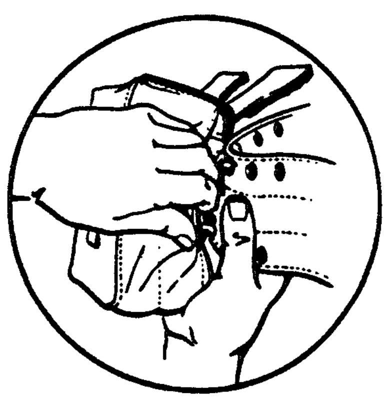


Figure 3.13: Component attachment to webbing

Many of the components which attach to the webbing consist of specialized pouches. The covers on the pouches close in the same manner as the pockets on the rucksack. The utility belt fastens around the waist with a large Fastex buckle. The utility belt can be made tighter around the waist or hips by pulling on a strap on one side of the Fastex buckle (figure 3.14).

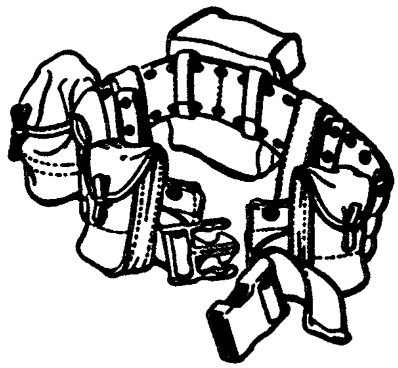


Figure 3.14: Webbing belt

Yoke The padded yoke is used to support the belt and various components (figure 3.15).

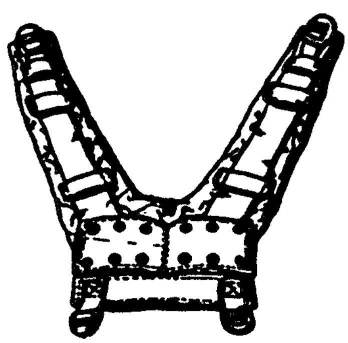


Figure 3.15: Webbing yoke

3.2.2 Personnel Evaluation of Design Features

The following data were collected through discussions with armed forces personnel at CFB Gagetown, New Brunswick and CFB Kingston, Ontario. These opinions are considered very valuable because these are the people with first hand experience with the load carriage system. Another important source of data is the observation of soldiers in action with their load carriage system. This will be pursued later in the project.

The data were obtained through five focus groups involving over 25 soldiers. A series of questionnaires was used to guide the discussion but were not extensively filled out by the soldiers. Though the questionnaires did not address all of the design features, several of those omitted were nevertheless brought out in discussion (Appendices 7.1 and 7.2). Opinions on the Canadian rucksack were also provided by civilian experts (see Appendix 7.3).

The following sections cover design features and to some extent ergonomics issues. Each section begins with a brief description of its contents. Then, the general requirements of each of the components are presented. The strengths and weaknesses of each design feature are grouped together under the heading 'Assessment'. Finally, the 'Improvement' section addresses the soldiers' efforts to compensate for design deficiencies as well as their suggestions on possible improvements. Of the many suggestions given, only the ones generally agreed on by several soldiers are reflected here.

a) **Frame** This section includes the design, durability, comfort, and practicality of the existing frame.

- **Requirements** The rucksack must be able to carry heavy loads up to 25-35 kg regularly, and occasionally over 45 kg and be able to be parachuted from an airplane or thrown in a truck without breaking or bending. It must be designed for comfort and durability.
- **Assessment** It is generally agreed by all soldiers that the present frame is not strong enough for the conditions it is subjected to. Some of the failures reported by the soldiers were bending of the corners, frame breaking at welding points, and frame cracking. Some soldiers reported that the bottom corners of the frame chafed their back. Shorter soldiers found the frame too long for them.
- **Improvements** A flexible metal frame that would conform to the shape of the back was

suggested by some soldiers to improve comfort. Other soldiers observed that very heavy loads and occasional exchanging of rucksacks with others precluded this alternative. Some expressed preference for a more rigid frame, such as on the 1964 Canadian pack, which could withstand impact more readily, and extend further from the back to promote air circulation. The old frame could also serve as a packboard.

b) **Lumbar Pad** This refers to the location, adjustability, and padding on the lumbar pad.

• **Requirements** The lumbar pad has to protect the back from the hard frame and provide some breathability in the back area. It should be adjustable for different body sizes and shapes.

• **Assessment** The current lumbar pad can only be positioned in two positions which are both very uncomfortable for some soldiers. Some say the lumbar pad is not effective.

• **Improvements** The lumbar pad should be longer, wider, and have more padding. It should also be more adjustable. Another possibility would be to have one single waist belt with a lumbar pad.

c) **Shoulder Straps** This includes the durability, comfort, and effectiveness of the shoulder straps and the buckles attached to them.

• **Requirements** The shoulder straps have to be strong enough to carry the heavy loads. They should carry these loads as comfortably as possible for the shoulder and be adjustable enough to fit a wide variety of body sizes. It should also have a quick release feature.

• **Assessment** The straps are not long enough to adjust for larger people or to allow an ample handle for tightening the load. The straps slip in the buckles and become loose during movement. The plastic clips break. The straps are very difficult to feed into the buckles because the ends are doubled over and sewn. Some soldiers report that the shoulder straps are angled so that they cause pain in the neck and shoulders. They also sometimes causes numbness in the arms or fingers. The discomfort of the shoulder straps seems to be caused by how tight they are pulled to stabilize the load, rather than by the amount of padding. Shifting of the weight helps to relieve the shoulders temporarily.

• **Improvements** To keep the straps from slipping in the buckles some soldiers tape the straps at the tension they prefer. This practice works well but is inconvenient in winter when the tape freezes. There is some disagreement as to whether the padding on the shoulders is thick enough but most soldiers agree that the padding on the shoulder straps should be extended further down the trunk of the body. The straps should be lengthened.

d) **Waist Belt:** This includes the comfort and functionality of the waist belt.

• **Requirements** The waist belt has to distribute some of the load from the shoulders to the hips and help keep the load from moving too much while performing vigorous activities. It has to fit over various layers of clothing.

• **Assessment** It was discovered that a large number of soldiers never use the waist belt. The reasons why varied: it took too long to get it undone in an emergency; some soldiers are not aware of the purpose of the belt; the belt is not designed very well so it does not transmit the load the hips well; and it is also a common practice, as a display of fortitude, to carry the full rucksack without the help of a waist belt. Those who do wear it say when it is cinched very tight it works quite well in preventing the rucksack from shifting.

• **Improvements** A padded waist belt which transmits load to the hips from the shoulders and keeps the load from bouncing as much as possible should be designed. The waist belt should also be able to be tightened from both sides of the Fastex buckle and have a quick release feature.

e) **Sternum Strap** The sternum strap connects the shoulder straps horizontally across the chest. The existing rucksack does not have one.

• **Requirements** The sternum strap should be designed to release with the quick release of the shoulder straps. It cannot interfere with breathing or equipment on the chest and it has to be able to fit women properly.

• **Improvements** There was disagreement as to whether a sternum strap would be useful. Some soldiers thought it would be beneficial because it would relieve some pressure on the arms. Others thought that it would restrict breathing. However it should be noted that most soldiers have never worn a rucksack extensively that has a sternum strap. The sternum strap could be designed so that it could be removed if the soldier chose not to wear it.

f) **Other Straps** This includes functionality of the straps that hold the valise to the rucksack, the load stabilizer straps, the pack reducing straps (compression straps), and the buckles on each strap.

• **Requirements** The purpose of the load stabilizer straps are to shift the center of gravity forward. The valise straps should hold the valise in position during long marches and vigorous activities. The pack reducing straps should compress the bag when it is not full so that the contents do not shift.

• **Assessment** The load stabilizer straps are mounted on the rucksack incorrectly so that it is impossible for the soldier wearing the rucksack to tighten them while moving. It was reported that the load stabilizer straps cause the shoulder straps to bunch on top of the shoulders. This causes blistering and chafing. Also, the load stabilizer straps are not very effective. The straps holding the valise to the rucksack do not work well. The valise comes loose from the pack causing it to bounce against the soldier. The plastic clips on the pack that the straps run through snap frequently in cold temperatures. The pack reducing straps do not decrease the volume of the rucksack enough for the smallest loads carried.

• **Improvements** The load stabilizer straps should be mounted in such a way that the soldier has to pull down on them to move the center of gravity forward. The straps attaching the valise to the rucksack should be thicker for more support for the valise. Most soldiers replace the current plastic slips with metal clips with teeth. This is effective in keeping the straps from slipping but it causes the straps to fray and eventually rip entirely. The compression straps should decrease the volume of the pack more.

g) **Pockets** This covers all aspects of the outside and inside pockets, and the main compartment including the closure of each.

• **Requirements** The pockets have to be easily accessible. The closures have to be quick and easy to use while wearing mittens, and secure the pockets in the closed position so that none of the contents fall out.

• **Assessment** The outside pockets are too small, especially when the inside of the pack is full. Most soldiers like the positioning and number of the present outside pockets. The closures of the outside pockets are acceptable for some but others think they are too awkward and slow to use with mittens on. In cold weather the plastic swells making it impossible to fit one plastic loop over the other. The overall volume of the rucksack is not adequate for the required contents. When a radio is placed in the pocket inside the main compartment there is little room for anything else. The covering flap over the zipper on the pocket on the lid is facing the wrong way causing it to get caught in branches and rain to flow down the soldiers back. Also, this zipper tends to give out frequently.

• **Improvements** The outside pockets should be made bigger. There is some disagreement as to whether detachable outside pouches would be practical. Some think it is a good idea whereas others feel that the present rucksack is almost always full so there would never be a time when the pockets are removed. They feel that it would probably be something else that could malfunction. The main compartment should be bigger. The most widely accepted suggestion for new closures would be a smaller version of the Fastex buckle that is on the waist belt. Velcro was rejected because it is ineffective when covered with mud or slush. Some suggested a combination of closures, whereby one would be able to close the pocket temporarily (maybe with Velcro) and a second device would close the pocket more securely but may take longer. The drawstring on the main compartment should be a tubular toggle instead of the present Y-shaped toggle.

h) **Valise** This includes the functionality of the valise and the closure system.

• **Requirements** The valise has to keep the sleeping bag dry.

• **Assessment** The soldiers seem to think that it is a good idea to have a separate bag to store the sleeping bag. The pouch on the old rucksack was too small to store the sleeping bag except in ideal conditions. There were also very good comments about the warmth and waterproof properties of the bivibag.

• **Improvements** The pull cord toggle on the valise should be rotated 180° so that it is easier to close. Presently the flap comes out of the valise when the drawstring is closed. The soldiers would like the flexibility to put the valise on the top or bottom of the rucksack. A problem with storing the valise on the top of the rucksack is that is restricts access to the rucksack.

i) **Material** This section refers to the strength and the waterproof properties of the rucksack's material.

• **Requirements** The material has to be waterproof, camouflaged, and lightweight. It cannot be brittle in the cold, tear easily, nor soil easily.

• **Assessment** The material tears on the corners of the frame however, it seems very durable otherwise. The rucksack is not waterproof, and the water absorbed by the straps and other pack material adds considerable weight to the load carriage system.

• **Improvements** Garbage bags are currently used inside the pack to keep the contents dry. A waterproof liner was suggested to replace the garbage bags.

j) **Loading Points** This section refers to the loading points on the outside and inside of the bag which are used to strap on ammunition and equipment, and handles to carry the pack.

• **Requirements** Presently a variety of equipment such as skis and snow shoes as well as ammunition may be strapped onto the outside of the pack. This is necessary due to the limited size of the bag and the need to reach ammunition quickly in an emergency.

• **Assessment** There are not enough loading points on the inside or outside of the pack. There is no handle especially designed for carrying the rucksack or throwing it into trucks.

• **Improvements** There should be loading points added to the inside and outside of the pack as well as a carrying handle. Presently the snow shoes are attached in an ad hoc fashion and most soldiers feel that snow shoes and skis are not used enough to justify special attachment points if it may sacrifice some other design features.

k) **Weight Distribution** This refers to the location of the center of gravity and how it affects balance, and the overall shape of the rucksack.

• **Requirements** The soldiers need the pack to be stable for manoeuvres where good balance is essential. When designing features such as pocket location or loading points weight distribution must be addressed. The ABCD (Access, Balance, Compactness, Danger) criteria outlined by an expert in the field with whom ERG consulted, Mark Coté, should be used when designing these features.

• **Assessment** The current valise holds much more than intended when designed. This disrupts the center of gravity, greatly lowering it. With a low center of gravity the pack becomes very unstable. The rucksack is almost always full. The soldiers feel that it is too thick (from the back outward) and bulky.

• **Improvements** Some soldiers favour the overall shape of the British Bergen pack which is longer and narrower, but comes higher over the head. The soldiers want the weight higher on their back. The rucksack needs to be redesigned so that the center of gravity is much closer to the center of mass of the soldier.

l) **Rucksack use during various activities** This section refers to behaviour of the pack when the soldiers are involved in activities such as marching as quickly as possible over long distances, running, going up a incline and descending a decline.

• **Requirements** The soldiers reported that they rarely run while wearing the pack. It is more of a shuffling motion where they move as quickly as possible. If there is a need to run the rucksack is jettisoned off. When running all the adjustments have to be made with one hand because the other hand is carrying the rifle.

• **Assessment.** Most of the soldiers reported that the rucksack and webbing bounce all over the place and all the straps and attachments come loose when moving quickly. The valise bangs against the lower back when running. The shoulder straps are pulled as tight as possible in an attempt to keep the rucksack from bouncing. This is very uncomfortable and contributes to the numb feeling some soldiers feel in their arms and fingers. It is virtually impossible to take part in activities such as crawling, or climbing while wearing the pack. The soldiers reported that there are no problems specific to climbing inclines, going downhill, skiing or snow shoeing. The shifting and bouncing are what makes these activities difficult while wearing the pack.

m) **Injuries** This section deals with some of the long and short term injuries caused by the rucksack.

The most common short term injury was bruising. The most common areas were the neck, armpits, top of shoulders, small of the back (caused by frame) and upper back. Chafing occurred on the shoulders (caused by load stabilizing straps) and underarms. Many complained of soreness in the back and shoulders, and swelling and numbness of the arms and fingers.

The most common long term injuries were bad knees and back but soldiers pointed out that this may have been caused by the overall weight they were required to carry not the design of the rucksack. Another long term injury was the loss of feeling in the fingers and arms for up to two weeks.

Rucksack palsy is a condition caused by carrying heavy loads on the back supported by straps that cross anteriorly over the shoulders. It causes numbness, paralysis, and/or pain in the hands and arms. Some of the soldiers were aware of the condition and had heard of instances of it occurring in the Armed Forces but none of the soldiers interviewed had ever suffered from it. One Unsatisfactory Condition Report (UCR) refers to an instance of rucksack palsy, where the overall load may have been at least as much to blame as the pack design.

n) **Fragmentation Vest (frag vest)** This section includes all aspects of the frag vest.

- **Requirements** The fragmentation vest's purpose is to protect the soldier from shrapnel, but it is by no means bulletproof. There was some dispute as to how often the frag vest was worn and who wore it, but most soldiers say that everyone in active theatre and training has to wear it. The load carriage system must be designed with this in mind.
- **Assessment** While wearing the frag vest, webbing and rucksack the motions of the soldier are limited considerably. The frag vest adds a lot to the overall weight. One advantage of the frag vest is that it distributes the weight of the pack throughout the shoulder area, somewhat relieving the arms. Shooting from the prone position is hampered because the frag vest interferes with the helmet, and is generally inflexible. The frag vest is very warm, and it chafes the underarms.

• **Improvements** Soldiers seemed to be in favour of combining the frag vest and the webbing into a load carrying vest that would also protect them against fragmentation. Some soldiers wanted the neck of the frag vest to be larger in diameter and higher (similar to the Netherlands's flack vest), which would provide more protection as well as being less restrictive around the neck area. Some soldiers had heard of the development of a frag vest which had the protective sheeting inside the vest arranged like shingles on a roof. They liked this idea because of the added flexibility it would give to the vest.

o) **Webbing** This section includes all aspects of the webbing.

• **Requirements** The webbing has to comfortably support the battle and fighting order loads. The components must be easily accessible in a battle situation. The soldier has to be able to perform activities such as crawling on the ground, running, and falling to the ground quickly. The closures on the magazine component of the webbing need to be able to be opened and closed very quickly.

• **Assessment** For narrow waisted people the minimum circumference required to accommodate the components is larger than the circumference of their waist. The straps of the webbing get in the way of the butt of the rifle when shooting. The magazine pouches need redesigning. Because of the time it takes to do up the magazine pouches they are often left open, resulting in lost magazines. The system of attaching the components is not generally liked. The plastic coupling hooks break with use or in cold weather and the grommets come out of the material leaving a hole that the coupling hooks cannot attach to. The components on the webbing bounce making running difficult. Some components, especially the magazine pouches are located in front of the hips. The soldiers explained that during an advance, they are continually diving to their stomach and getting up. The components dig into the soldier's hips when they fall quickly to the ground. However, overall the webbing is far more accepted than the rucksack.

• **Improvements** The magazine pouches should be located on the chest instead of the hip area so the soldiers can easily reach them while shooting from the prone position. As mentioned in the section on the fragmentation vest, most soldiers like the idea of a load carriage vest.

3.2.3 Actual versus Prescribed Uses of Load Carriage Equipment. Because of the inadequacies of the current rucksack many adjustments have been made. Many soldiers do not follow the guidelines set out for them in military handbooks. The reasons for the deviations from the guidelines include the impracticality of some guidelines in the handbook, different constraints and needs of different trades, the experience of the soldier (cutting down on unnecessary kit items), and 'traditions' in various units.

The webbing is worn on top of the rucksack by some soldiers for long marches. The webbing may be slung over the backpack, attached to the pack with the waist and shoulder straps, or tied on to the pack with small pieces of string. This is done because of the awkwardness of wearing both the rucksack and the webbing at the same time. The small field pack on the webbing gets in the way of the rucksack and the components of the webbing get in the way of the waist belt. This practice is considered dangerous by some soldiers because of the time it would take, in an emergency situation, for the soldier to take the webbing off the pack and assemble it for fighting order.

The soldiers are told to carry in their valise only the air mattress, sleeping bag (liner and inner), utility sheet, mosquito bar, and wash basin (Winter, Marching Order, Annex A, TO USO 12-30). Most soldiers put in their valise everything they will carry into the tent with them, or the equipment needed to set up their own shelter. This includes all the above mentioned kit items plus a hand towel, and shaving kit (razor blades, razor, shaving brush (optional), shaving lather, soap, soap dish, tooth brush, and tooth paste or powder), and bivi bag. This is done because the valise is easy to remove from the rucksack and there is only enough room in the tent to fit the soldier and their valise. This practice makes the valise a lot heavier than it was designed to be, adversely affecting the center of gravity. The extra weight in the valise may also be what causes the straps that hold the valise onto the pack to slip as much as they do.

It was discovered through conversation with the soldiers that the waist belt is not used by many. The reasons varied from soldier to soldier. Some soldiers are not aware of the advantages of the waist belt, especially the aspect of weight transmission to the hips. However, the waist belt on the current rucksack does not do a good job of transmitting the load properly. It does not sit on the hips as it should. It wraps around the stomach area on some soldiers which can restrict breathing. Another reason for not using the waist belt is that is does not have a quick release mechanism. If the pack has to be taken off in a hurry, precious seconds are lost taking off the waist belt. It is also a common practice, as a display of fortitude, to carry the full pack without the help of a waist belt. The benefits of wearing an effective waist belt are many including physiological benefits and the ability to efficiently and comfortably carry heavier loads.

The actual contents of the rucksack tend to deviate from the prescribed contents as the soldiers get more experienced in the field. The soldiers are often expected to carry much more ammunition than the regulation books show. To compensate for this extra volume and weight of ammunition the soldiers leave out items such as extra socks, underwear and rations.

Several different models of fragmentation vest have been tested by the forces. The frag vest which has pockets in the chest area is sometimes converted into a load carrying vest as well as a frag vest. The components are attached to the utility belt of the webbing and the belt is attached to the hooks on the side of the frag jacket. Other components are placed in the pockets on the chest of the frag vest.

The traditional rule of thumb for the maximum weight of load carriage for a typical working day is one-third body weight, which is 25 kg for a body weight of 75 kg (Haisman, 1988). During the visit to CFB Kingston, armed forces personnel reported that the heaviest loads they typically had to carry were approximately 25-35 kg. These loads were carried over a distance of 16-18 km in a time frame of 2-2.5 hours. However, instances of carrying loads in excess of 45 kg have been reported. In the absence of regulations enforcing maximum weight limits, implications of carrying heavier loads should be considered in any design of load carriage equipment. It is important that in designing a new pack this discrepancy between actual operating procedures and prescribed operating procedures be taken into account.

3.3 *U.S.A. Military Load Carriage*

The American military employ more than one type of pack, depending on the unit in question. The Special Services pack in particular has been praised by Canadians who are familiar with it. However, the pack which we had available to examine is more widespread.

The design features of the medium combat field pack with frame obtained from the United States Armed Forces were reviewed (figure 3.16). This pack has a total volume of approximately 32.8 litres and a weight of approximately 2.8 kg unloaded including the frame. It is approximately 53 cm high by 40 cm wide by 25 cm thick when fully loaded.

a) **Frame:**

- there is an external pack frame made from aluminum tubing and straps
- a cargo support shelf and cargo tie-down straps can be attached to the frame to carry water cans, ammunition cases, etc.
- there are two plates attached to the lower sides of the frame which extend 10 cm horizontally towards the back of the person wearing the pack, the waist belt attaches to these plates with straps
- the frame attaches to the pack by inserting it up into a 15 cm deep pocket on the top of the pack and attaching it with straps on the bottom of the pack

b) **Padding:**

- there is approximately 1 cm thick padding between the pocket the frame is inserted into to and the carrier's back
- 1.5 cm thick and 5 cm wide padding on the shoulder straps
- there is a rectangular shaped lumbar pad attached to the waist belt which is 15 cm high, 1.5 cm thick and 45 cm long

c) **Adjustability:**

- the point of attachment of the shoulder straps to the top of the pack cannot be adjusted vertically
- the shoulder strap adjustment changes the length and tension of shoulder strap
- the waist belt strap is adjustable in length from both sides of the Fastex buckle
- there is no sternum strap

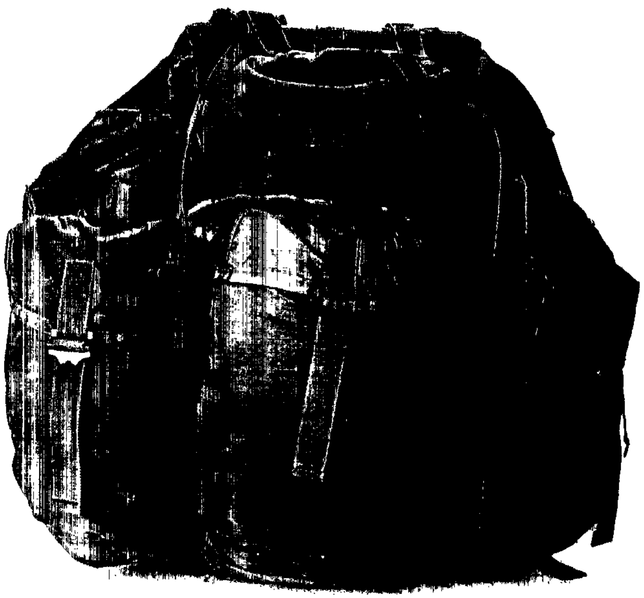


Figure 3.16 American Pack

Figure 3.17 British Pack

d) Pockets:

- one large inside compartment with a Y-shaped drawstring closure and an overflap which closes with straps that attach to metal buckles on the bottom of the pack
- there is a pocket on the inside of the pack designed to fit a AN/PRC 25 or 77 radio; it has a strap with a metal buckle but no covering flap
- there are three pockets on the front of the pack that have double closure mechanisms: metal buckles and hasps
- the middle pocket on the front of the pack is approximately 4 litres and the pockets on either side of this pocket are approximately 2 litres each
- there are three small pockets of approximately 0.5 litre each with cover flaps and hasp closures which are located above the middle pocket on the front of the pack

e) Attachment Points:

- there are eight flat material lashing points on each side of back pocket

f) Compression Straps:

- no compression straps

g) Quick Release:

- there is a quick release mechanism on the shoulder straps
- a small tab is pulled which pulls a hasp apart, the rest of the quick release is a metal version of the closures on the Canadian rucksack (section 3.2.1)

h) Carrying Handles:

- there are no carrying handles

i) Extras:

- the bag is made of a water repellent treated duck and webbing

3.4 *U.K. Military Load Carriage*

The design features of the internal-frame short back rucksack obtained from the British Armed Forces was reviewed (figure 3.17). This pack has a total volume of approximately 73 litres and a weight of approximately 3.4 kg unloaded. It is approximately 56 cm high by 30 cm wide and by 21cm thick when fully loaded.

a) Frame:

- removable internal metal frame consisting of 3 vertical bars attached by pin connection at top to one horizontal bar
- the frame is inserted into a pocket inside the bag that has three vertical columns, one for each of the vertical bars
- the pocket for the frame is closed with a Velcro overflap

b) Padding:

- approximately 1.5 cm thick padding the over entire surface which comes in contact with the back
- 1.5 cm thick and 5 cm wide padding on the shoulder straps
- 1.5 cm thick padding on the waist belt which extends 15 cm from sides of the pack in a triangular wedge

c) Adjustability:

- the point of attachment of the shoulder straps to the top of the pack cannot be adjusted vertically
- the lower shoulder strap adjustment changes the length and tension of shoulder strap
- waistbelt strap is adjustable in length, but it sits on the bottom of the ribcage and can only be used to stabilize side to side motion and does not bear any weight of the pack
- there is no sternum strap

d) **Pockets:**

- one large inside compartment with an inner and an outer Y-shaped drawstring closure
- small (approximately 3 litres) pocket on the bottom of the back of the pack with a zipper closure and a Velcro overlap
- two detachable side pockets (approximately 12 litres each) which attach with zippers and buckles and have a zipper closure with an overlap
- inside pocket on lid
- outside pocket on lid which is accessible from left side of the person wearing the pack

e) **Attachment Points:**

- eight flat material lashing points on the lid
- two hanging loops on lower front
- two strips (approximately 1.5 ft. long each) of attachment points going down back of pack (one on either side of back pocket)
- four attachment points on exposed surface of detachable pocket, four on surface of pocket which attaches to pack; attachment point with buckle on bottom of detachable pocket, and two on inside of zipper cover flap
- four flat material lashing points on sides of back pocket
- one tie-able attachment point above back pocket
- two flat material lashing points on bottom of the pack
- none on inside of lid

f) **Compression Straps:**

- three horizontal compression straps on each side

g) **Quick Release:**

- no quick release mechanism

h) **Carrying Handles:**

- one carrying handle on the front of the pack between the shoulder straps

i) **Extras:**

- all zippers are one way
- lid has elastic on each side
- equipped with straps running from the top of the bag to the shoulder straps which are designed to pull the centre of gravity forward

3.5 *Summary of Review of Current Systems*

Some of the critical design features culled from the packs described above are reproduced here. It is not meant to be an exhaustive list, but rather to highlight several of the salient points. It is evident that certain design elements are poor, while others are very useful. Furthermore, there will naturally be contradictions in the acceptability of certain features depending on the use and the user. For example, a larger pack would allow more space, but perhaps at the expense of comfort, or safety, or convenience, etc.

Following a synopsis of design features, a few sections are devoted to discussing the process of developing better load carriage systems.

3.5.1 Summary of Important Design Features

Access

- The pockets should be easily opened and closed while wearing mittens.
- The pockets should be easily accessible while marching.
- The components on the webbing must be easily accessible in a battle situation.
- The magazines should be located on the chest for easy access while lying in a prone position.
- The components on the webbing should not interfere with activities such as crawling on the ground, running, and falling to the ground quickly.
- The waist belt should be able to be tightened form both sides of the Fastex buckle.

Anatomical Fit

- The shoulder straps, lumbar pad, and waist belt must accommodate armed forces personnel with a wide variety of body shapes and sizes including females.
- The sternum strap has to be adjustable vertically on the shoulder straps to accommodate armed forces personnel with a wide variety of body shapes and sizes including females.
- The frame has to be designed in such a way so that it will not dig into the lower back of personnel with smaller body sizes.

Comfort

- The sternum strap must relieve pressure on the arms and not interfere with breathing.
- The waist belt has to distribute from the shoulders to the hips.
- The waist belt has to fit over various layers of clothing.
- There has to be sufficient padding on the waist belt and shoulder straps so that they do not dig into the body.

Durability

- The frame has to be able to carry heavy loads up to 61-80 lbs regularly, and occasionally over 100 lbs and be able to be parachuted from an airplane or thrown in a truck without breaking or bending.
- The frame must not bend at the corners or break.
- The plastic clips on the shoulder strap, valise, and waist belt must be strong enough to carry the loads of a soldier, must not be brittle in the cold, and must not slip causing the straps to come loose.
- The zippers should not break.
- The plastic coupling hooks which attach the components to the webbing should not break in cold weather and the grommets on the webbing belt should not come out of the material leaving a hole that the coupling hooks cannot attach to.
- The material of the rucksack has to be waterproof.

Stability/Balance

- The waist belt has to keep the load from moving too much while performing vigorous activities.
- The stabilizer straps should be designed in such a way that the soldier can move the center of gravity of the pack forward without cinching the shoulder straps tightly on the shoulders.
- The stabilizer straps should be mounted in such a way that the soldier has to pull down on them to move the center of gravity forward.
- The pack reducing straps (compression straps) should compress the bag when it is not full so that the contents do not shift causing stability problems.
- The valise straps should hold the valise in position during marches and vigorous activities so that it does not come loose and cause stability problems.
- The soldiers would like the option of placing the valise on the top or the bottom of the pack depending on how much weight is required to be carried in it.
- The soldiers favoured the design of a pack which was longer and narrower for more stability while moving.
- The soldiers want the center of gravity located high in the pack.

Modularity

- The fragmentation vest should be combined with a load carriage vest.
- The rucksack has to be designed so that there is a removable compartment that cam be carried into the tent with the soldier. (Similar to the present valise.)
- There has to be sufficient loading points both inside and outside the rucksack so that equipment such as ammunition, skis, and snowshoes can be attacked and hung off the bag easily.

3.5.2 *Integration of Load Carriage Components*

It is imperative that whatever type of load carriage system(s) is designed for the military, it must work well with existing equipment and be able to adapt to the equipment presently being designed. For this to be achieved all equipment must be designed with a systems view. The IPCE project provides a unique opportunity to develop clothing, equipment and load carriage systems that are fully integrated. To be successful, the load carriage system limits would apply some constraints on the total weight, volume, and shape of kit items under development. Conversely, prioritization of kit items with respect to accessibility, weight, frequency of use and other parameters should drive the load carriage design to respond optimally to these needs. Of course, the interface of load carriage system with the kit items is only one facet of the design objective, another important one being the suspension system coupling the load and the soldier.

For example, the difficulties encountered with the present system highlight some of the obstacles which could be overcome with a new system. The fragmentation vest, webbing, and rucksack should work together to ensure the soldier is well protected from frag but also has manoeuvrability and is able to access the components on the webbing. The present system restricts movement considerably. Some soldiers report that the bulk of the frag vest, webbing, rucksack, and winter parka make it impossible to reach the quick release. With all this equipment on, the quick release sits on the shoulder where it is most conveniently activated with the soldier's teeth. There are several materials on the market today such as Gortex and polar fleece which ensure warmth and waterproof properties while reducing the bulk and weight of the clothing.

The present webbing and rucksack do not work well together. The components of the webbing get in the way of the waist belt on the rucksack, the small field pack gets in the way of the rucksack and the two sets of straps on the shoulders are awkward. Most soldiers seem to be in favour of developing a load carriage vest which would incorporate the webbing and the frag vest.

Another important consideration is the design of the equipment that the soldier has to carry in the webbing or rucksack. The equipment should be designed with load carriage as well as usability in mind. The positioning of the components is also very important. Access to the most commonly used and emergency equipment will determine where things are placed. One of the better aspects of the current webbing is its flexibility to carry different equipment.

3.5.3 Testing Protocol for Design Features

A new rucksack must meet many special conditions to be suitable for military use. Some of the following conditions have already been met by the present rucksack and must also be present in a new design. Before manufacturing each condition must be tested on a prototype to set minimum standards. During manufacturing these standards must be met. The packs as well as the people being tested will be both civilian and military.

The first set of tests would be mechanical lab testing. The design features such as the material, buckles, and straps would be tested for strength, durability, and other mechanical properties. The loads that would be applied in each test would reflect the loads typically carried by soldiers including the maximum that would have to be carried.

The next set of tests would be human factors and ergonomics lab testing. They would include testing for comfort, posture, physical effort needed to support loads, stability, and fit of various packs. Physiological, biomechanical and performance assessment tools can be applied to quantify these various parameters.

Circuit testing and field testing will be the last two sets of tests. Both will complement some of the tests performed in the lab to obtain more complete results. An important variable in circuit testing will be time. From the field tests we will assess the interaction of the packs with the environment and the durability of the packs under realistic conditions.

Through these four sets of tests standards will be developed and maintained.

4. REVIEW OF SCIENTIFIC LITERATURE

The scientific literature review can be divided into three main categories of study based on these primary foci: physiological studies; biomechanical studies; and performance studies.

4.1 *Physiological studies*

Physiologically-based research articles and reports have investigated variables such as load weight, placement of the load, walking speed and distance covered, environmental conditions and walking on grade. Physiological measures of these variables have included heart rate, pulmonary function, metabolic costs, perceived exertion, blood pressure, creatine phosphokinase serum level and blood lactic acid levels. Researchers have also included subjective measures, i.e. ratings of perceived exertion, as a psychological complement to physiological responses.

4.1.1 Heavy Load Carriage. A review of the literature reveals a number of studies that have described the severity of load carriage tasks, in particular, for military personnel (Cathcart et al. 1923; Renbourn, 1952; Goodman, 1965; Soule et al. 1978; Legg and Patton, 1987). Renbourn (1952), cited an indictment by Rifleman Harris against a badly balanced load of about 60 lb carried by soldiers during a long retreat in the Peninsular War of 1808 and he quotes "the knapsack was our worst enemy in this prolonged march. Many a man died, I am convinced, who would have borne up to the end of our retreat but for the infernal load we carried on our backs. My own knapsack was my bitterest enemy....".

In 1952, a report by Hunter and Turl appraised the methods employed by the Canadian Infantry for carrying loads into battle and made recommendations for lightening, redistributing and improving the combat load. As well, they recommended that improvements be made in carrying methods. Their major concerns indicated in the report, were that infantrymen had been required to approach the limit of their physical endurance under battle conditions, not always allowing reserve physical strength for engagement. It was their recommendation that 18 kg (40 lbs) be recognized as the maximum efficient combat load and that efforts be made to lighten all items of personal and combat equipment particularly the helmet, pick, shovel, rifle and ammunition.

McCaig and Gooderson (1986) found that with the addition of support weapons, radios and extra equipment the total weight carried by British soldiers during the Falklands operation escalated to very high figures, for example 68 kg, for military operations. In their summary of questionnaire results, after interviewing approximately 2000 soldiers returning from the conflict, 20% listed fatigue due to the total weight carried and the length of marches as a significant problem.

The Army Development and Employment Agency branch of the United States Army prepared a report in 1987, which stated that the foot soldier was overloaded and that it was critical for commanders to be trained to take into account factors such as load, the physical state of troops, acclimatization and terrain when planning march durations and speeds.

The Human Factors Division of the Canadian Defence and Civil Institute of Environmental Medicine in November 1994 summarized the following equipment information: the weight listed for Marching order/MAW gunner is 70.636 kg and for Marching order/Radio operator 66.212 kg.

It can be concluded that the modern army continues to require the transport of heavy load weight by personnel on foot.

4.1.2 The Search for an Acceptable Weight. There have been attempts to define an upper limit to the weight that soldiers should carry in order to avoid injury and undue fatigue. In a report for the U.S. Army, the Army Development and Employment Agency (1987) made the point that the soldier load problem is quite complex because of the number of variables that exist. For example, the ability of a soldier to carry a load can depend on many factors such as terrain, climate, physical fitness, nutrition, leadership and morale. And what constitutes the load to be carried can depend on a variety of elements including: the type of mission, the enemy, the terrain, the number of troops available and the timing factors. They also make a valuable point worthy of consideration, that speed of movement can be as important a factor in causing exhaustion as the weight of the load carried. Load carrying can cause fatigue placing the soldier at a disadvantage when rapid reaction to the enemy is required. Therefore when loads become heavier, speed of march must be reduced. The conclusion of their extensive report is that maximum fighting load of 22 kg (48 lb) is acceptable; that approach march load should be limited to 33 kg (72 lb); and, that emergency approach march load be between 54 kg and 66 kg (120 and 145 lb) when contact with the enemy should be avoided.

Yu and Lu (1990) found that 20 kg was an acceptable load for male Chinese soldiers to carry in the field for 7 hours while marching at 5 km/hr, based on energy balance, heart rates and subjective sensation. The soldiers marched for 50 minute intervals with a 10 minute rest in between and they stopped for 1 hour at lunchtime. These results are in agreement with Shoenfeld et al. (1977), who concluded that maximal back load of more than 25 kg for a 20 km march at a speed of 5 to 6 km/hr will affect a well-trained individual's ability to perform work afterwards. Epstein et al (1988) tested subjects carrying 25 kg and 40 kg while walking on an elevated treadmill (5%) for 2 hours. They found that the 40 kg load resulted in work at 52% MVO2, 20 minutes after the beginning of the walk. Their study implied that increases in load causes physical fatigue, once work intensity surpasses 50% maximal work capacity. Holewijn (1989) recommended, upon completion of studies with male and female Dutch soldiers, that the capacity of the metabolic system restricts the total load to 37 kg for the male soldier and 22 kg for the female soldier. He added that these loads should take into consideration the weight of clothing, helmet, boots and weapons.

The 15 male subjects of Patton et al. (1991) walked 12 km at speeds of 4 km/hr, 4.86 km/hr and 5.67 km/hr with external loads of 31.5 and 49.4 kg carried in a standard US Army load carriage system consisting of a rucksack with external frame and additional foam rubber padding placed under the shoulder straps. Still, five subjects were unable to complete one or more of the 49.4 kg load carriage trials. The researchers concluded this was primarily due to severe discomfort in the neck and shoulder area. Results indicated that to prevent an increase in oxygen consumption over time, while carrying a load of 31.5 kg the march rate would have be less than 4.86 km/h and for a load of 49.4 kg, rate of march would have to be less than 4 km/h.

A study published in 1994 by Sagiv et al., gave new meaning to the upper limit of load weight that could be carried comfortably by male subjects, over a continuous four hour treadmill walk. All subjects completed the study while carrying loads of 38 kg and 50 kg on a level treadmill at a constant speed of 4.5 km/hr, without difficulty (no significant differences in subjects' ratings of perceived exertion from minute 5 to minute 240). Results indicated that mean values of heart rate, diastolic, and mean arterial blood pressures, cardiac output, rate pressure product (heart rate x systolic blood pressure), and oxygen uptake were significantly higher during exercise with 50 kg than with 38 kg of weight. No significant differences were found between the two different loads with regard to systolic blood pressure, end diastolic and systolic volumes, stroke volume, ejection fraction, systemic vascular resistance, wall stress, posterior wall thickness, and rate of perceived exertion. This study suggested that, during prolonged exercise (4 hours) with heavy load carriage, there is a steady state in oxygen uptake, heart rate and blood pressure responses throughout the course of effort. These results are not in agreement with Epstein et al. (1988) or Gordon et al. (1983). These suggested that during 120 min. of exercise there is no steady state and that energy cost gradually increases. The results of Sagiv et al.(1994), however, were supported by Soule et al. (1978), who showed that energy cost per kg is the same, even up to a maximum of 70 kg, when the load is well-balanced, and close to the centre of the body. Soule et al. (1978) employed 14 male subjects in their study, who attempted walks of 45 minutes at speeds of 3.2, 4.8 and 6.4 km/hr. The average completed time at 6.4 km/hr with 60 kg was 18.5 min, with 65 kg was 15.5 min and with 70 kg was 8.3 min. Researchers speculated that limits to load-carrying capacity may arise from poor positioning of the load itself, rather than from weight per se.

Sagiv et al. (1994) gave two reasons why their subjects were able to complete their strenuous tests without undue fatigue or complaints, and why their results differed from the other researchers' results. The first reason was the design of the backpack itself, which they reported included new shoulder straps, and hip and chest belts that helped distribute the load to the large muscle groups of the hips and legs, allowing a better mechanical efficiency. Ratings of perceived exertion also reflected the fact that their subjects had not reached fatigue even though some were carrying 66% of their body weight. The other reason for the differences was attributed to an incorrect approach by Epstein et al. (1988) in calculating percentages of submaximal effort while carrying a load.

A number of investigations into load weight have been undertaken outside the realm of the military. Pierrynowski et al. (1981) measured the metabolic costs of load carriage and concluded that a load carrier's own body mass should be considered in the maximum weight equation. This suggests differing weights be carried by differently-sized people, an idea that deserves more consideration. Winsmann and Goldman (1976) compared load carriage systems and concluded that provided the weight is properly distributed over the body, weight per se is the most important factor in load carriage, rather than the specific load-carriage system design. It would seem that recent literature does not support this notion, i.e. Sagiv et al. (1994). Buono et al. (1989) looked at serum creatine phosphokinase response of walking with various backpack loads for a 12 hour period on the treadmill. Subjects alternated walking for 20 min and resting for 40 min. Researchers concluded that an increase in skeletal muscle damage occurred with an increase in backpack load of greater than or equal to 50% of body weight, based on levels of serum creatine phosphokinase.

The search for the maximal acceptable weight has traditionally placed emphasis on the amount of weight carried. However, as noted from the scientific research available, a wide range of factors such as speed of walking, total distance covered, duration of carry, terrain conditions and grade, physical fitness, and the design of the load carriage equipment all play important roles in the limits of weight that can be carried safely and productively. The scientific literature that has been reviewed gives excellent descriptions of many of these above noted factors which directly affect the acceptable limits of load weight carried. However, researchers in many cases, have not included enough detail about the designs of the packs they have used in the studies.

4.1.3 Load Placement. The physiological approach has also been used to study placement of the load. Legg (1985) provided an excellent review of scientific literature which had looked at different methods of load carriage. He first cited the classical study by Bedale (1924) on the efficiency of eight different methods of carrying loads. She found that energy expenditure was least while carrying the load using a yoke across the shoulders, compared to on the hip, trays, hand bundles, the head and over the shoulder. Datta and Ramanathan (1971) comparing seven different ways of carrying a load of 30 kg over 1 km at 5 km/hr, found that the double pack (front and back) incurred the least oxygen cost, and that loads in the hands incurred the most. Legg and Mahanty (1985) are in agreement that the double pack (front and back) was the most efficient, when compared to carrying the regular backpack, and a trunk jacket method (i.e. version of a flak jacket). This method of carriage may be impractical to use, however, in many realistic military and outdoor activities.

Among Legg's (1985) conclusions were: loads are most frequently carried in the hands or arms, or on the back usually by backpack or knapsack; for greatest efficiency and stability, the load should be kept as close to the trunk and centre of gravity of the body as possible; and he speculates, that local muscle fatigue is an important element in the factors which limit load carriage "...when a load is carried using a backpack, it may be discomfort in the back, shoulder or neck muscles rather than physical exhaustion that often limits the man's ability to continue". Legg et al. (1992) used male soldiers to compare heart rate and oxygen uptake of two methods of carrying field artillery ammunition. The researchers designed a backpack frame to which ammunition (shells of 18.4 kg and charges of 7.6 kg) could be attached with straps. They compared this method of load carriage with carriage directly on the shoulders and found that backpack load carriage is associated with a lower heart rate and oxygen uptake.

Another way of looking at load placement is to consider the actual concentration of the mass in relation to the load carrier. One of the first studies to look at this problem was by Hinrichs et al. (1982), who examined the inertial properties of backpacks. There results are limited, however, as they only looked at the loaded pack alone, not the carrier-backpack system. Among their conclusions, based on mechanical principles were: the backpack should be as light as possible, it should be as close to the body as possible, it should be symmetrically designed to minimize postural change and that the pack should possess as small a moment of inertia as possible, particularly around the Y (forward & back movement) and Z (vertical) axes. Bobet and Norman (1984) investigated the effects of two different load distributions (just below mid-back or just above shoulder level) on heart rate as well as muscle activity. Although the two load placements affected EMG activity in two groups of muscles, the heart rate was not affected. They concluded that the metabolic measures were not sufficient to adequately assess tasks which evoked primarily local muscle demands.

Holewijn and Lotens (1992) became interested in the effects of different positions of load mass on the physical capabilities of infantry soldiers. Tests employed included an obstacle course, jumping, sprinting, running, hand-grenade throwing and a mobility test. Disturbance of balance was defined as the displacement of the centre of gravity of the "subject + mass" combination, compared to the normal position of the pelvis. A posterior displacement of the centre of gravity (more to the back) was created by placement of the mass low on the back (blocks of lead in the backpack weighing 16 kg). A posterior displacement of the centre of gravity in combination with a displacement upwards was achieved by placement of the weight on the back at shoulder level. Almost no disturbance of position of the centre of gravity was created by distributing the mass around the waist. Results of the study indicated that performance, averaged over all the tasks, was 1.5 to 2% better with an equally distributed mass around the waist compared to mass low or high on the back. Also by placing the mass high on the back, acceleration of the upper body was slowed, which resulted in a poorer performance on the mobility test.

It can be concluded from these load placement studies that for greatest metabolic efficiency, the load should be kept as close as possible to the trunk and the centre of gravity of the body. More research is needed to examine the effects that different placements of the mass of the load have on the carrier. In general, heavy loads should not be carried using small muscle groups and optimum use should be made of the large muscle groups in order to minimize fatigue and local muscle discomfort.

4.1.4 Prediction of Physiological Cost. The search for the limit of load a soldier should carry led researchers to devise a formula whereby the energy cost of load carrying could be predicted with reasonable accuracy (Giovani and Goldman, 1971). These researchers initially used a mathematical equation which included the weight of the person, the load and the walking speed. Extra energy required for walking on uneven or difficult terrains can also be estimated using terrain coefficients (Soule and Goldman, 1972). In 1974, Haisman and Goldman compared measured and predicted energy costs for backpacking on blacktop and a dirt road at two speeds. They found that predicted values underestimated energy costs during the slower speed of walking (0.89 m/sec).

Pandolf et al.,1977, revised the predictive formula on energy expenditure to include measures of: metabolic cost for standing without load; the metabolic cost of load bearing while standing; the metabolic cost for walking on the level; and the metabolic cost for climbing grade. This predictive model of metabolic cost was limited, however, to standing or walking with and without loads but was not applicable for walking speeds above approximately 2.2 m/sec or running. At higher speeds, the efficiency of running becomes higher than that of walking, which meant that the prediction model of walking overestimated the actual energy cost of running (Margaria et al. 1963; Keren et al. 1981). Epstein et al. (1987) developed a mathematical prediction equation which allowed the prediction of the metabolic cost of walking and running at a wide range of speeds, external loads and grades. The equation as originally published by Pandolf et al. (1977) is:

$M_w = 1.5W + 2.0(W + L)(L/W)^2 + n\,(W + L)(1.5V^2 + 0.35\, G \circ V)$, (in Watts) where M_w = metabolic rate (Watts), W = nude body weight (kg), L = clothing and equipment weight (kg), n = terrain factor, V = walking velocity (m/sec), G = grade (%).

Epstein et al. (1987) added:

$M_r = M_w - 0.5\,(1 - 0.01L)(M_w - 15L - 850)$, (in Watts)

where M_r = metabolic cost of running (in Watts)

4.1.5 Ratings of Perceived Exertion. In 1970, Borg researched and developed a simple scale for ratings of perceived exertion to complement measures of physiological stress. This was done initially so that health workers could discontinue work tests with patients with health problems at a safe time and modify exercise intensities to levels which best suited the patients. The scale consisted of 15 grades numbered 6-20, giving ratings of perceived stress from very, very light to very, very hard. A subject, during the work test, answered verbally or points to a rating chart. The Borg scale has been used extensively by physiologists to aid in evaluating load carriage systems (Ekblom and Goldberg, 1971; Winsman and Goldman, 1976; Robertson et al., 1982; Gordon et al., 1983; Goslin and Rorke, 1986; Juhani et al., 1986; Legg and Mahanty, 1986; Ramsay et al., 1989; Kirk and Schneider, 1992; Holewijn et al., 1992; and Sagiv et al., 1994).

Initially, perceived exertion was considered to reflect the feelings of strain which arose from two sources: working muscles and the cardio-pulmonary system (Ekblom and Goldberg, 1971). Juhani et al. (1986) used the Borg scale with soldiers to compare load carriage methods of skiing with a backpack and skiing while sledge hauling. The soldiers rated the sledge hauling 21-28% less strenuous. The comparative physiological results showed that differences in heart rate and oxygen consumption, between the two methods of carriage, were significant with the highest load (100% of the carrier's weight). Balogun et al. (1986) compared three modes of carriage at three speeds of walking: headpack, transverse yoke and frontal yoke, using measurements of oxygen uptake, local ratings of perceived exertion and ratings of overall perceived exertion. It was their reasoning that an ergonomic device should not only be metabolically efficient but be subjectively acceptable to the user. They chose to analyze separately, local sensations of discomfort associated with strap pinching and pressure on bones and muscles. They discovered that ratings of overall exertion did not differ significantly among the three modes of carriage, but the *local* ratings differed significantly between the load carriage methods and these ratings were supported by the trends in metabolic response.

Goslin and Rorke (1986) examined the effects of backpack load carriage on ratings of perceived exertion (RPE) with ten well-conditioned male subjects. They carried 0, 20 and 40% of body mass in an external frame backpack at two speeds normalized for stature. Steady-state ventilation, cardio-respiratory and RPE data were collected. Results indicated that with the exception of breathing frequency, ventilatory, cardio-respiratory, and RPE responses increased linearly with increases in load carried and relative speed. One of their more interesting discoveries was that as soon as the load was carried, the perception of exertion increased 1.5 to 2 times the increase in measures of central physiological response, and that after this initial change, the increase in added load (to 40%) had little further effect. They attributed this abrupt change in RPE, relative to respiratory response, to the increase in level of muscular tension, joint compression, alterations in locomotor posture, kinaesthetic sensations from skin, tendon and ligament, and the stretch receptor feedback. Goslin and Rorke (1986) do make the point that dividing perception of exertion into categories of "central" and "local" factors may be a rather simplistic approach to a complex phenomenon.

Kirk and Schneider (1992) used Borg's scale in their research on load-carrying responses in female subjects using external-frame and internal-frame backpacks. They evaluated ratings of perceived exertion for the chest, shoulders and legs while subjects carried

33% of their body weight while walking on a treadmill at 5.1 km/hr for one hour. The subjects walked on level grade for 15 minutes, then the treadmill grade was elevated to 3% for 15 minutes and then lowered to level for 15 minutes and so on. They found that the type of pack frame carried did not cause any statistically significant differences for the ratings of perceived exertion (RPE) for the chest, shoulders or legs. These results are in agreement with Patton et al. (1990) who found no significant differences in RPE (among other measures as well) for male subjects carrying US army internal- and external-frame backpacks. Interestingly, though, Kirk and Schneider (1992) did find that exercise duration and the increase in treadmill slope caused significant increases in the RPE for the shoulders and legs. Changes in treadmill grade had a significant effect on oxygen consumption, heart rate and minute ventilation as well.

These researchers have speculated that the most important aspects of backpack design may be the padding, fit and general comfort rather than the specific frame type (external versus internal). As well, it is their recommendation that evaluations of load-carrying systems should include measures of metabolic, cardiorespiratory, perceptual and biomechanical responses to determine any subtle differences that may exist which cannot be detected through metabolic and cardiorespiratory data alone.

4.2 *Biomechanical studies*

Many of the same variables such as load weight and placement, pack design and distribution of the load have been examined in this category of research. There are fewer studies using biomechanical measures but results seem to show greater sensitivity to subtle differences in pack characteristics. Biomechanical measures in research of load carriage have included: electromyography (EMG); film analyses of posture, gait patterns, and balance; force platform measures of ground reaction forces; and pressure sensing gauges used to identify forces on the body.

4.2.1 Electromyography (EMG). Electromyography (EMG) has been used as a technique by several researchers to discern differences in effects due to loads (Neumann and Cook, 1984; Cook and Neumann, 1987; Knapik, 1989), and load placement (Holewijn, 1990; Bobet and Norman, 1984).

Bobet and Norman (1982) measured surface EMG from the tibialis anterior, vastus lateralis, biceps femoris, erector spinae (lumbar portion) and upper trapezius muscles of the right-hand side of the body of subjects carrying an external frame backpack. Subject's carried loads of 20, 25 or 32 kg; the loads were carried "high" (50 cm above iliac crest) or "low" (20 cm above iliac crest); and the EMG were collected at each of 5, 37 or 97 minutes. These authors reported that there is potential for average full wave rectified EMG measures to be used to as a method of analysis for whole-body tasks. However, they identified areas of potential difficulty: muscle substitution (subjects adopted new body positions as load increased), different motor patterns between subjects (so pooling EMG from several subjects may be misleading) and a third potential area of difficulty being the statistical power of the technique and it's ability to detect statistically significant differences (suggesting that a fairly large subject pool be employed). Nonetheless, within a subject, fairly useful data can be gathered to explain within-subject differences.

Neumann and Cook (1984) looked at the effects of carrying position and load weight on EMG of the gluteus medius muscle during the stance phase of the gait cycle. Results indicated higher EMG activity for a load of 20% of body weight carried in front of the body with the arms than for that same load carried in a pack on the back.

Researchers compared a biomechanical measurement technique (EMG) and physiological methods (telemetry measuring heart rate) to look at the effect of two different load placements (Bobet and Norman, 1984). Their reasoning was that while metabolic measures reflected the total work rate of the body, they gave no indication of whether local loading of relatively small but potentially vulnerable muscles was excessive. Subjects carried 19.5 kg in a backpack while they walked at an average of 5.6 km/hr on a level surface. EMG activity in erector spinae and upper trapezius muscles was measured. The load placed in the high position resulted in significantly higher levels of muscle activity than did the lower placement. Heart rates were not significantly different between the two placements.

Cook and Neumann (1987) carried out a study that was similar to their 1984 study, but this time looked at paraspinal muscle activity under four load conditions and in addition, male and female subjects were studied to determine amounts of back muscle activity based on gender. They concluded that use of the backpack in carrying minimizes the muscular requirements on both sides of the spine and that carrying with the arms, anterior to the chest, elicited the maximum EMG activity for the four conditions. Female subjects showed significantly greater erector spinae activity than males using the anterior (arm) carrying position.

4.2.2 Film Analysis. Film analysis has been another method of biomechanical technique used to compare types of load carriage systems (Bloom and Woodhull-McNeal, 1987; Martin and Nelson, 1986). Filming, combined with ground reaction force data computed by a force platform is another technique used to look at the biomechanics of load carrying. Martin and Nelson (1982) used high speed cinematography techniques to film subjects walking with different load configurations. They were studying walking gait, and therefore used just one camera in the sagittal plane of the body and filmed at 50 frames per second. Results suggested that major differences in the data (stride length, stride rate, stride velocity, single leg contact time, double support time, swing time and trunk angle) were due to gender, while changes in load and pack had little influence on the variables examined. In general the men had longer stride lengths and lower stride rates than women. Also there was little difference in trunk angle between women and men. The researchers concluded that the measures used did not detect any meaningful differences between the backpacks or the loads.

Devita et al. (1991) studied a pack carried with a vertical shoulder strap on the left side. Ground reaction forces were obtained as well as frontal and sagittal plane film records. Results indicated general body imbalance, as well as unilateral and unbalanced use of the trunk muscles on the non-loaded side.

4.2.3 Force Platform. The force platform can measure the centre of pressure, as well as forces applied and moments of force. The benefit of the force platform is that it can simultaneously measure three force components along the x,y,z axes, as well as three moment components about the x,y,z axes. Nelson and Martin (1982) used the force platform to compare the performances of four different backpack systems (three external-frame and one internal-frame) while subjects took a position of "easy standing" with a variety of typical military loads. Male and female subjects held a comfortable stance on the force platform, which measured their centre of pressure, and the forces applied, under the various conditions. Both men and women found the middle weight loads easier to balance and, in all cases, the internal frame was easier to balance than the external frame. It is not clear whether the researchers in fact controlled for position of the load's centre of mass.

Martin et al. (1981, 1982), in a comprehensive study, examined the effect of frame length, pack load, and participation times for men and women on a number of tasks, wearing four different sizes of external frame pack (the frames differed in length only). The battery included a series of performance test movements, treadmill walking and running, and an easy standing stability measure on the force platform. Increased load altered the gait pattern as shown by film and force plate analysis. The frame length conditions employed in the study had little influence on the physical performance of the subjects. These lengths were: the standard 20 inch, a personally-sized frame (P), a P plus 2 inches and a P minus 2 inches. Based on subjective ratings of comfort, frames which are too short should be avoided.

4.2.4 Pressure Sensors. A novel approach was identified in the literature with the potential to show effective results. Holewijn (1990) placed pressure sensors on the shoulder straps to identify the forces experienced by the shoulders. Using these sensors, he recommended that loads be transferred to the hipbelt where the skin area is less sensitive to pressure. The use of pressure sensors is relatively new in biomechanics and has primarily been used to assess the pressure under the foot in gait or on a chair when seated. However, this technology will provide excellent feedback for pack evaluation and possibly individualized fitting procedures.

4.3 *Performance Studies*

Renbourn (1953) wrote a comprehensive and historical account of the knapsack with particular reference to the British soldier. He emphasized the importance of including performance tests that can simulate military tasks, and that are carried out under the realities of the field, among the various methods of investigation in order to give a more complete appraisal of the problem. He concludes his paper with some ideas that are worthy of note, now, 40 years later. "Soldiers are essentially standardized and uniform with regard to clothing worn, equipment used and loads to be carried. However, in height, weight, muscular efficiency and physical fitness, soldiers are predominantly individuals. Hence, the effect of a load, or a particular load carrying equipment, varies appreciably from soldier to soldier; and in that same soldier, with climate and terrain, training and experience and state of morale. It follows, therefore, that the scientist can plan the experiment, take the relevant data and then advise; but the final decision will always have to come from the commanders in the field, who alone are intimately conversant with the soldier's function, and the purpose of their equipment". As yet, there is not a system in place which can help the commanders in the field make good load carriage decisions for their soldiers.

A series of performance-based research projects were carried out under the direction of the Human Factors Group of the Individual Protection Laboratory at US Army Natick, (Nelson and Martin, 1982). The purposes of these trials were to evaluate modifications and innovations in the design of pack systems, and to look at the expanded role of women in field operations. The subjects were representative of the military population in height and weight but were in fact university students. The first study researched the effects of gender and load on combative movement performance by putting the subjects through a series of seven performance tests, including: 10- and 25-yard sprints, agility run, standing long jump, reaction movements to the left and right, and a ladder climb. The loads varied from a fighting gear condition of 9 kg, to a maximum of 36 kg for women (60% of mean body weight) and 43.5 kg for men (65% of mean body weight). The results of this paper were limited to the conclusion that a systematic increase in load produced a systematic decrease in performance, and body size was not consistently associated with performance across the tests.

The second Martin and Nelson (1982) study was designed to compare four frame-pack systems, three external frames (ALICE LC-1, ALICE LC-2, and PACKBOARD) and one internal frame pack (LOCO). Two external-frame packs consisted of a nylon, top-loading pack bag that sat on a frame made of aluminum tubing, with aluminum flat stock as horizontal and vertical supports. The shoulder straps, lumbar pad and the hip belts which attached to the external frame, were the main differences in the two packs. The packboard was made of flat aluminum stock with a similar harness system as the ALICE LC-2. The internal frame was a top-loading commercial pack made by Lowe Alpine Systems. Subjects were undergraduate students enrolled in the university army program. They performed movements of easy standing and the vertical jump, under six different load conditions, on the force platform. The researchers found that the internal frame allowed for greater postural stability relative to the three external-frame systems.

The third portion, studying the biomechanics of load carrying behaviour by Martin and Nelson (1982), examined the effects of gender, load and backpack type on the temporal and kinematic characteristics of the walking gait. The data collection consisted of filming the walking gait of each subject under several different load and pack configurations. One walking speed was used, namely 6.4 km/hr and the four pack types, as described in the second portion of this study, were used again. Analyses of the data indicated that there was little difference in the trunk angles maintained by the men and women. There was a tendency for subjects to decrease stride length and increase stride rate as the load was increased. Few differences in the characteristics of walking gait could be attributed to differences in backpack design.

Information obtained from military personnel after field operations can be an invaluable source of knowledge regarding evaluations of equipment and physical fitness of soldiers, as well as limitations of human load carriage (Renbourn, 1953; Joy and Goldman, 1968; McCaig and Hickman, 1992) . McCaig and Gooderson, 1986, interviewed troops returning from a military conflict in the Falkland Islands. Their survey included questions with reference to cold weather clothing, physical fitness and limitations of load carriage. With regard to load carriage, information from group interviews revealed that troops were surprised by the weights they were required to carry, which ranged from 31 to 68 kg. (The researchers calculated that for an average weight of 50 kg the 50th percentile infantryman would have been carrying 70% of his nude body-weight.) Problems which occurred due to the fatigue from carrying heavy loads included: sprained ankles, discomfort from pouches rubbing on the legs and backache from local pressure from rucksacks. As well, the heavy load carriage resulted in equipment failure, including: bent and broken metal buckles, webbing material being frayed or holed, shrinkage, water absorption, and manipulation of straps difficult with cold wet hands.

In 1992 the Department of the Army, Fort Benning, Georgia carried out a tactical field demonstration in order to evaluate the operational potential of their SIPE technologies (soldier integrated protective ensemble). The published results were made available in an extensive report to the Infantry School and NATICK Research Centre. In the summary of results regarding the load bearing component, soldiers reported by questionnaire that the weight was distributed toward the lower portion of the body, causing balance problems and discomfort to the lower back and hip area. Specific deficiencies were noted in the weight distribution, interface with other components, frame configuration and stability of the load bearing component.

4.4 *Summary of Scientific Findings*

Scientific evaluation of load carriage has been accomplished through three main areas of study, namely, physiology, biomechanics and performance studies. Contributions to the study of load carriage have come from a long history of military- based research, civilian-based research (sometimes supported by military grants), and civilian research within the context of the outdoor recreation industry.

A summary of the Physiological area of research is as follows:

1. Physiological measures have been used to assess energy demands during many methods of load carriage. Specifically, energy expenditure as been calculated through measures of heart rate, cardiac output, minute ventilation, and oxygen consumption, for particular work rates.
2. Relevant variables which have been shown to directly affect work rate are: amount of load carried, the position of the load mass on the body, the speed of movement (walking/running/marching), the grade at which movement is occurring and the climatic conditions.
3. Physiological studies have been used extensively in attempts to define the acceptable load for marching and/or fighting soldiers, for example:

a) The U.S. Army Development and Employment Agency in their report on the soldier's load initiative (1987), recommended that: approach march load (contact with the enemy is unlikely), not exceed 32.7 kg (72 lbs), and fighting load (essential combat items), should not exceed 22 kg (48 lbs) based on physiological research.

b) Holewijn (1989) of the Netherlands Organization for Applied Scientific Research stated that loads for male soldiers should be restricted to 37 kg and for female soldiers 22 kg at a walking speed of 5.2 km/hr. He further recommended that during combat situations loads be further restricted to 9 kg for the male and 6 kg for the female soldier. Holewijn predicted that for walking speeds of over 4 km/h, the acceptable weight be reduced by 20 kg per 1 km/h of speed based on physiologically- based research.

c) Scientists Yu and Lu (1990) recommended that 20 kg was an acceptable load for male Chinese soldiers to carry for 7 hours while marching 5 km/hr (soldiers marched 50 minutes and rested 10 minutes).

d) According to Canadian National Defence standards (1982), the following principles were listed: soldiers can carry loads of up to one third their body weight for prolonged periods with little adverse effect. Loads in excess of one third body weight will have a cumulative effect which is proportional to the increase in weight and time carried.

4. With regard to load placement, research indicates that for greatest metabolic efficiency, loads should be kept as close to the trunk and centre of gravity as possible. In general, heavy loads should not be carried using small muscle groups and optimum use should be made of the large muscle groups in order to minimize fatigue and local muscle discomfort.

5. Prediction equations have been used to determine the metabolic cost of load carriage during experimental situations that would not allow for direct measure such as a study involving a face mask, respirator or helmet. They have also been used when the value of the energy cost data does not justify the cost, effort and equipment use of actual measurement. Predictive measures could be useful to predict metabolic energy costs in the field or workplace where scientific procedure would be intrusive.

6. Rating scales which measure perceived exertion have been used to complement physiological measures of work-related stress. The subjective scale has been shown to be valuable in assessing local muscle fatigue and pain, that had not been indicated by a metabolic response, such as high heart rate.

A summary of the Biomechanical Research is as follows:

1. Methods of biomechanical research employed in load carriage analyses have included: evaluation of muscle activity through electromyography; kinematic data received from film analysis; mathematical and mechanical analyses of centre of mass, inertial properties and linked-segment models; ground reaction force measures obtained by the use of the force platform, providing data on balance and stability; and, skin pressure data have been obtained with miniature pressure transducers.
2. Potential areas of difficulty for the use of average full wave rectified EMG in whole-body tasks (such as the study of load carriage) were identified (Bobet and Norman 1982). These included: muscle substitution (the subject adopts a different movement pattern or body position due to fatigue or added load); different motor patterns between subjects can occur (even though they are doing the same task), therefore pooling EMG data can be misleading; and the ability of the statistical procedure to detect significant differences caused by increased variability within- subjects and between subject data.
3. The effects of load placement on erector spinae EMG and trapezius EMG (Bobet and Norman, 1984) indicated that high load placement, which caused more swaying, increased activity by the trapezius musculature.
4. Comparisons of two backpacks have been successfully made using EMG data (as well as film analysis, heart rate and rates of perceived exertion) (Norman et al., 1986). EMG was able to show differences (between packs) in local muscle activity; EMG data showed that level walking at 5.54 km/h, as a test procedure, produces greater local muscle differences attributable to design than did stepping over barriers at 3.29 km/h; and, EMG responses were sensitive enough to be able to measure two relatively close regions of the lumbar region.

5. Film analysis of load carriage has provided data of stride length, stride rate, single leg support time, double-support time, swing time and forward inclination of the trunk. Results indicate that female subjects generally require higher rate of stepping than males (due to shorter stride length); generally, walking patterns are affecting by load carriage (stride length and swing time shorten, stride rate increases); and forward inclination of the trunk increases with 29 kg and 36 kg loads (Martin and Nelson, 1986).
6. Miniature pressure transducers (Model 156, Precision Measurement Company, USA) were used to measure pressures under the shoulder strap on the skin (Holewijn, 1990). The amount of pressure and the duration of the pressure both contribute to irritation, subcutaneous oedema and inflammation of the dermis and underlying tissue. Pressure applied on the skin under the shoulder straps should be below 10 kPa (75mm Hg). Researchers recommend transfer of weight to the hips to reduce the shoulder pressure.

A summary of the Performance Studies area of research is as follows:

1. Most Army agencies have recognized that the foot soldier is overloaded. It follows, therefore, that the value of knowledge regarding load carriage is limitless, whether it be knowledge of the load weight carried or the carriage system itself. It is difficult to quantify these performance studies in such a manner as to identify one common pack, pack load distribution, or pack type which is favoured by all military personnel under all conditions, thus pointing out the necessity for a pack which is quite variable and which can suit the individual preferences of each soldier.

5.0 REPORT SUMMARY

Although the Advanced Personal Load Carriage System project is aimed at future demands and equipment, it is instructive to review current systems for a number of reasons. The objectives of this review were to gain an appreciation of historical load carriage systems, current military and commercial load carriage systems, and relevant scientific results in the realm of load carriage.

This review has highlighted many design and ergonomic factors related to load carriage systems. General characteristics of packs were outlined in the background report on the evolution and current state of load carriage equipment prepared for the Ergonomics Research Group, and in the popular literature. Characterizations by design features, comfort, ease of use, versatility and other parameters are commonly performed. Similar categorizations have been used in this report to evaluate the Canadian army's load carriage components, U.S and U.K. military packs, and a commercial pack. In some cases, there are clear deficiencies in some design elements. However, in many instances the success of a particular configuration is individual and/or task and/or environment specific. For example, buckles that work well during three seasons of the year, may be inoperable in winter conditions. A tall pack may be ideal for some due to its large capacity, but impractical for short people to carry. One of the main benefits of this review has been a better understanding of the interplay amongst these factors.

The process of load carriage system design and development has also been given some attention. The foremost observation is that a load carriage system should be designed in conjunction with the development of other military clothing and equipment, and that full attention should be paid to ergonomics at all stages of the development process. On the former issue, the IPCE project provides a unique opportunity to coordinate the soldier's gear from a systems point of view. On the latter point, several comments have been made in this report on soliciting suggestions from field officers on possible designs, and obtaining feedback from troops during field trials at various stages of system development, as discussed further below. As well, attention should be paid to commercial pack developments and feedback from civilian trekkers because much of this type of information is cutting edge, and relevant to the development of a military load carriage system.

Several guiding design principles have emerged while conducting this review. The design and development work can be broken down into two categories — existing and advanced. A "Concept I" approach assesses and generates design elements based on existing technology and current understanding of load carriage principles and backpack design, both civilian and military. The criteria and procedures of the Concept I approach are currently under development. Using the Concept I framework, it is clear that the existing Canadian pack can be improved in a number of ways to provide identifiable and significant advantages with respect to existing uses and users. Such modifications could help in the field, and would also lead to better understanding of performance. However, the changes developed and proposed by this method would be primarily evolutionary as opposed to breakthrough.

As the design work moves to a more advanced stage, three advanced approaches should be considered:

a. Accept the existing design approach to load carriage and other associated components (or "subsystems") and thus separately attempt to improve closely related and interacting components such as the pack, kit, upper body clothing, flak jacket,and webbing;

b. Consider the potential for redesign of some new advanced overall "system" approach to load carriage design, and consequently redefine the sub-components of such a new system to yield a more coordinated and effective final result;

c. Use the combined strategies of (1) and (2).

Based on the work to date, we recommend the third approach and we are confident that there are distinct possibilities for breakthroughs as a result. To maximize the potential and significance of these, the design approach should additionally emphasize the following:

i. Continuation of the determination of general good design guidelines for load carriage abstracted from related experience, experiment, and theory;

ii. Carefully coordinated and cooperative determination of the various uses and requirements for Canadian military load carriage, including but not limited to those traditionally accomplished by packs. This should include past, future, and potential requirements, and involve significant inputs from the ultimate users and field personnel and the developers of related future strategies and equipment.

A design/development approach which rests heavily on inputs and experience generated with existing designs and tasks, will also inherently provide for rapid user feedback on various concepts and prototypes as the advanced development proceeds. This is important because the "need" for an improvement or change is frequently not foreseen, and only recognized after users are given a chance to try out the improved version. A simple example might be the positive reaction of many members of the military after trying an internal frame pack for the first time. Of course this approach can also quickly expose disadvantages, defects, and suggested modifications. For example, the sharp edge on the lower part of the Canadian pack frame would have been discovered and changed prior to issue, had this design approach been used. This load carriage review has thus revealed shortcomings of previous design processes, as well as suggesting improved method as outlined above.

Scientific and popular literature on load carriage design elements and performance ratings has also been summarized in this report. Many studies have been performed to assess the effects of load carriage on humans. Factors studied included total load, load distribution, and various load carriage systems. Conditions range from forced marches of several days to balance, treadmill or circuit tests in the laboratory. Formal assessment methods are mostly based on physiological or biomechanical measurements or ratings of perceived exertion.

The principal conclusions of the scientific literature review are that biomechanical measures and subject perceptions can be good indicators of design variations in the load carriage system. Generally, physiological measures are not sensitive enough to reflect subtle changes in configuration, although they provide very useful information on the effects of total load and environmental conditions. Furthermore, the relationship between user perceived stress under load and quantitative measurements is not very well developed. That is, a quantifiable, repeatable measure of the ergonomic merit of a load carriage design is still an open area of research, which ERG is undertaking in this project.

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7.0 APPENDICES

APPENDIX 7.1 Questionnaire used at CFB Gagetown

This was the first in a series of questionnaires developed to solicit feedback from military personnel on the current Canadian personal load carriage equipment. Suggestions for improvements were also encouraged.

The questionnaire was not distributed, but served rather as a guide for interviewing focus groups. Based on the responses obtained at CFB Gagetown, this questionnaire was then refined and subsets of it used for the interviews at CFB Kingston (Appendix 7.2).

Advanced Personal Load Carriage System Study
Queen's Ergonomics Research Group

Questionnaire

1. Fill out all questions if possible.
2. If you wish to expand on any answer use reverse of sheet.
3. If none of the choices to some questions are suitable, please write in any answer you prefer.
4 Please provide rank. Rank____

The following questions refer to Marching Order which consists of Battle Order plus those items of equipment necessary to support a soldier in the combat zone for an indefinite period of time.

1. a) Do components of the pack fail?
   _ yes _ no

   b) If yes, check all that apply.
   _ straps
   _ rivets
   _ grommets
   _ fabric tearing
   _ seams tearing
   _ buckles
   _ other____

2. Is the pack waterproof?

   _ yes, in light rain/snow. _ yes, in heavy rain/snow. _ yes, totally. _ not at all.

3. Which type of closure do you prefer?
   _ zippers
   _ velcro
   _ buttons
   _ buckles
   _ metal hasps
   _ pull cord
   _ other____

4. a) Has your frame ever bent or broken?
   _ yes _ no

   b) If yes, to what extent?

5. Would you prefer a more flexible frame that would contour more to the shape of your back?
   _ yes _ no

6. Is your pack typically full or does the volume of its contents vary a lot?
   _ full _ varies

7. a) Do you use the compression straps?
   _ yes _ no _ sometimes

   b) If yes, which ones?

8. Are there enough compression straps in the pack to ensure the smallest loads you carry are not moving inside the pack?
   _ yes _ no

9. Do attachments to your pack (ex. sleeping bag) stay in position? Explain.

10. Would you rather have one large compartment on the interior of the bag, as you have now, or several compartments?
    _ One large compartment.   _ Several compartments.
    Comments:

11. Would you like more outside pockets?
    _ yes   _ no

12. Would detachable outside compartments be useful?
    _ yes   _ no

13. Does the pack have sufficient points of adjustment for you to make it fit to your body size and shape?
    _ yes   _ no

14. Where are more adjustments needed?

15. How much would you estimate your pack to weigh (on average) when loaded?

    _ 40-60lbs   _ 61-80lbs   _ 81-100lbs   _ 101-120lbs

16. a) What approximately is the maximum weight carried in the pack?

    _ 41-60lbs   _ 61-80lbs   _ 81-100lbs   _ 101-120lbs   _ more________________

    b) What activity were you engaged in while carrying the maximum weight?

    c) How long was this activity?

17. Do the straps on the pack have sufficient padding while wearing:
    _ a T-shirt
    _ a light jacket
    _ a fragmentation vest
    _ a winter jacket

18. What effect does wearing the fragmentation vest have on the pressure points of the pack?

19. Are the straps:
    _ too wide?   _ too narrow?   _ just right?

20. Do the straps cut off circulation to the arms?
    _ never   _ occasionally   _ often   _ always

21. Are the straps around the neck area:
    _ too close to the neck   _ too far apart on the shoulders   _ just right.

22. a) If there was a sternum strap, would you use it?
    _ yes   _ no
    b) Why or why not?

23. If a quick release mechanism was designed to release the pack with one pull a of a strap, what straps would you like included in the quick release mechanism? (Check all that apply.)
    _ right shoulder
    _ left shoulder
    _ waist strap
    _ sternum strap

24. a) Do you employ the waist strap?
    _ yes **(If yes, omit question #25)**
    _ no **(If no, omit question #26)**

    b) Why or why not?

25. a) If the waist strap had a quick release, would you wear it?
    _ yes _ no

    b) Why or why not?

26. If you use the waist belt please answer the following questions.

    a) Where is most of the weight concentrated? Waist or shoulders?

    b) Where would you prefer most of the weight to be concentrated?

27. Do you think you would employ a strap from the top of the pack to the shoulder strap, common to many commercial packs, that brings the centre of gravity of the pack closer to your centre of gravity?
    _ yes _ no

28. a) Do you find yourself shifting your pack's weight regularly?
    _ yes _ no

    b) How often?

29. What shifting adjustments do you make and what part of the body does this relieve? (ex. lifting the pack forward with hands placed on the bottom behind the bag to relieve the shoulders, pulling the bag forward with the straps to relieve the lower back.)

30. Is your pack:
    _ too wide? _ just right? _ too narrow?

31. Is your pack:
    _ too long? _ just right? _ too short?

32. Where would you prefer that the heavy load is placed in your pack?
    _ low back
    _ upper back
    _ evenly distributed

33. In which areas of the body do you feel the most discomfort and pain after you are marching with your pack for **an hour**? (Indicate 1st, 2nd, 3rd, etc.)

_ neck
_ shoulders at straps
_ upper back
_ lower back
_ knees
_ ankles
_ feet
_ other____

34. In which areas of the body do you feel the most discomfort and pain after you are marching with your pack **all day**? (Indicate 1st, 2nd, 3rd, etc.)

_ neck
_ shoulders at straps
_ upper back
_ lower back
_ knees
_ ankles
_ feet
_ other____

35. Have you had any long term injuries from wearing the pack? (Example, rucksack palsy, pulled muscles) If yes, please detail.

36. Of packs from other countries or commercial packs that you have seen, please give some features that you would like to see on your pack.

Running

37. Does the bag bounce so much that running becomes difficult?

_ yes _ no

38. a) Are you able to adjust the pack while running?

_ yes _ no

b) If yes, what adjustments do you make?

_ Tighten the shoulder straps.
_ Loosen the shoulder straps.
_ Tighten the waist strap.
_ Loosen the waist strap.
_ No adjustments.
_ Other____

39. Is the pack too wide to swing your arms properly while running?
_ yes _ no

40. a) Does the pack require readjustment after a sudden stop?
_ yes _ no

Comment:

b) If yes what adjustments do you make?

Marching up an incline:

41. Does the bag bounce so much that marching up an incline becomes difficult?
_ yes _ no

42. When going uphill what aspects of the pack hamper movement?

43. Does the pack affect stability or balance when going uphill? Explain.

Marching down an incline:

44. Does the bag bounce so much that marching down an incline becomes difficult?
_ yes _ no

45. When going down hill what aspects of the pack hamper movement?

47. Does the pack affect stability or balance when going downhill?

Battle Order

The remaining questions refer to wearing Battle Order equipment which consists of the webbing and those items of ammunition, equipment, and rations necessary to support a soldier in combat for a period of time not exceeding 72 hours.

48. Does the webbing have sufficient points of adjustment for you to make it fit to your body size and shape?
_ yes _ no

49. Where are more adjustments needed?

50. a) Do components of the webbing system fail?
_ yes _ no

b) If yes, check all that apply.
_ straps
_ rivets
_ grommets
_ fabric tearing
_ seams tearing
_ buckles
_ other________________________________

51. Which attachments have flexibility in their position on the webbing and where are they attached?

52. Which attachments have fixed positions, and where are they located?

53. Which attachments are hardest to reach and where are they located?

54. a) Do you ever wear the fragmentation vest with the webbing?
_ yes _ no

b) If yes, approximately what percentage of the time do you wear them together? ______________

c) Can the fragmentation vest be worn in place of the webbing?
_ yes _ no

d) What are the problems associated with wearing the two together?

55. Do the webbing straps have sufficient padding?
_ yes _ no

56. Are the webbing straps:
_ too wide? _ too narrow? _ just right?

57. Do the webbing straps cut off circulation to the arms?
_ never _ occasionally _sometimes _ always

58. Are the webbing straps around the neck area:
_ too close to the neck _ too far apart on the shoulders _ just right.

59. a) Do you find yourself shifting the weight of the webbing around regularly?
_ yes _ no

b) If yes, how often?________________________________

c) If yes, what points on the body are you trying to relieve?

60. Are there any other comments you would like to make concerning topics you feel we have no covered sufficiently? Elaborate on any features of the current load carriage system that you like or dislike.

APPENDIX 7.2 CFB Kingston questionnaires and responses

The following are the responses to a series of questionnaires obtained from 21 members of the 1st Signals Regiment, CFB Kingston, during a site visit on Feb. 8, 1995. The first written questionnaire was filled out by the soldiers. The percentages given in question 5 of the written questionnaire were derived by assigning an answer of 'Poor' 0% and an answer of 'Excellent' 100%. The responses were then averaged. The writing in bold are the most common answers the soldiers gave.

The following three questionnaires were used as a tool to initiate discussion. The soldiers were broken into three smaller focus groups, each of which was expected to respond to at least two of the verbal questionnaires. The oral responses the soldiers gave are given in bold after the question.

The following preamble was provided at the start of each questionnaire:

> The Queen's University Ergonomics Research Group is currently undertaking a project, sponsored by The Defense and Civil Institute of Environmental Medicine (DCIEM), to develop an Advanced Personal Load Carriage System (APLCS). This research will provide valuable human factors input for the load carriage component of the Integrated Protective Clothing and Equipment (IPCE) project.
>
> The following questionnaire will assess what combat troops feel about the present load carriage system and solicit ideas for the design of a new load carriage system. A number of questions relate to the 1984 rucksack and Marching Order in general, followed with questions about Battle Order. Your answers and comments will be extremely helpful for this study.

QUESTIONNAIRE ANSWERED IN WRITING BY ALL PARTICIPANTS

1. Height: ____________________ Weight: ________________

2. Does the rucksack cut off circulation to the arms?

   _ never _ occasionally _ often _ always

Comments:
- **mostly occasionally, few often and few never**
- **after long hikes: shoulders sore, numbing in arms**
- **uncomfortable when worn with webbing**
- **movement of arms is limited when snaps are pulled snug**
- **shifting the strap location helps**

3. Are the shoulder straps:

   5_ too close to the neck? **2**_ too far apart on the shoulders? **14**_ just right?

Notes:
- does not correspond with height or weight

Comments:
- **not enough cushioning on the straps**

4. Does the pack have sufficient points of adjustment to make it fit your body size and shape?

   12_ yes **8**_ no

Comments:
- **across the chest**
- **needs belt in front**
- **frame too long**
- **shorter people have problems with frame being too long**
- **rucksack are same size regardless of person size**
- **adjustments not at right place, need more at shoulders**
- **too many in wrong place**
- **more adjustment to raise load higher on back**

5. How do the following aspects of the pack fit?

a) Frame: 1 ----------------2---------------- 3 ----------------- 4 ---------------5
Poor Excellent

Comments:

- **The group rated it 55%.**
- **Frame too long, slides down too low, would prefer it in the centre of the back**
- **Old pack fit better, more water resistant.**
- **Sometimes too big.**
- **Not flexible enough.**
- **Should be stronger.**
- **Digs in at small of back, more back padding.**

b) Shoulder straps: 1 ----------------2---------------- 3 ----------------- 4 ---------------5
Poor Excellent

Comments:

- **The group rated it 55%.**
- **Needs to be a little narrower.**
- **The stabilizer straps are upside down. They are impossible to adjust when the pack is on.**
- **The quick release is located on shoulder when winter parka is worn which makes it too high to reach. (One subject used her teeth to release it, because she couldn't reach it with her hands.)**
- **The quick release pull tabs are too small (less than 5 cm), hard of grasp.**

c) Lumbar pad: 1 ----------------2---------------- 3 ----------------- 4 ---------------5
Poor Excellent

Comments:

- **The group rated it 59%.**
- **Needs to be in centre of pack.**
- **Needs to be better.**
- **More padding.**
- **If your body size is between settings it doesn't really work.**
- **Make it wider across back.**
- **Make it longer.**
- **No noticeable effect.**

d) Waist belt: 1 ----------------2---------------- 3 ----------------- 4 ---------------5
Poor Excellent

Comments:

- **The group rated it 50%. This does not include two people who didn't answer because they didn't use it.**
- **Add padding.**
- **Restricts breathing.**
- **Excellent with heavy loads.**
- **When wearing a parka it is useless, useful in summer when it can be cinched tight**
- **One person's Fastex buckle kept coming undone.**
- **It was good that it could be removed it they didn't want to wear it.**
- **Both of the women used it and found it useful.**

6. Have you had any short term injuries from wearing the pack? (i.e. bruising, chafing, blistering, numbness in arms or fingers.) If yes, please detail.

Comments:

- **If they fall down they can't get up by themselves, they also can't put them on by themselves when fully loaded.**
- **Sore shoulders from heavy weight.**
- **Lower back pain on longer marches.**
- **Numbness in arms and fingers on long marches. (Many responses.)**
- **Shoulder cramps.**
- **Chafing underarm.**
- **Bruising. (Many people said this.)**
- **Bruising armpits, low back pain, cuts off circulation in arms.**
- **Chafing, numbness in arms and fingers.**
- **Bruising at top of shoulder in neck area.**
- **Chafing and numbness in back and arms.**
- **Fingers swell, stretch marks on shoulders.**
- **Sore, bruised from heavy loads.**
- **Bruising and chafing at small of back. (X2)**
- **Bruising upper back.**

7. Have you had any long term injuries from wearing the pack? (i.e. rucksack palsy, pulled muscles) If yes, please detail.

Comments:

- **Pulled muscles. (Caused by overuse.)**
- **Not yet.**
- **Bad knees and back but unsure of cause.**
- **Numb hands for two weeks.**
- **Fell forward during night march, ruck fell against back of head and injured neck.**
- **Knee injuries, back pain, shin splints.**
- **A lot of training is done on roadways.**
- **Stiff neck and sore shoulders from tightening the shoulder straps in order to have free movement of lower body.**

QUESTIONNAIRE #1 AND RESPONSES

1. a) Do components of the pack fail?
   _ yes _ no

   Universal agreement that components fail

   b) If yes, check all that apply.
   Y _ straps
   Y _ rivets
   Y _ grommets
   Y _ fabric tearing
   Y _ seams tearing
   Y _ buckles
   _ other____________________

   - **Sleeping bag carrier; zippers are weak; hooks on webbing; plastic ladderlocs broke frequently on shoulder straps when tightened; zippers split; straps that hold valise in place frayed due to replacing plastic ladderlocs with metal clips; fabric worn out at rub points; belt buckle gave way when tightened; grommets pulled out.**

2. Is the pack waterproof?

   _ yes, in light rain/snow _ yes, in heavy rain/snow _ yes, totally Y_ not at all.

   - **Yes, in light snow.**

3. Which type of closure do you prefer?
   Y _ zippers
   Y* _Velcro
   _ buttons
   Y _ buckles
   _ metal hasps
   _ pull cord
   _ other____________________

*** only with a backup method, like fastex clips on pockets, fastex buckles - quick release**

LOAD CARRIAGE DURING VARIOUS ACTIVITIES

A) Running

4. Does the bag bounce so much that running becomes difficult? Y _ yes _ no

   - **lower section especially sleeping bag, loosens.... webbing bounces, webbing interferes**

5. a) Are you able to adjust the pack while running?
Y _ yes N_ no

- **Tighten the waist and tighten the shoulders, bend over to tighten the straps (i.e. some said yes, but with difficulty)**

b) If yes, what adjustments do you make?

Y _ Tighten the shoulder straps.
_ Loosen the shoulder straps.
Y _ Tighten the waist strap.
_ Loosen the waist strap.
_ No adjustments.
_ Other____

- **bend over, shift pack up and tighten the shoulder straps**

6. Is the pack too wide to swing your arms properly while running? _ yes N _ no

7. a) Does the pack require readjustment after a sudden stop? Y _ yes N _ no

- **tighten shoulder straps, the load falls down**

b) If yes what adjustments do you make?

- **tighten the sleeping bag and mattress up**

B) Marching up an incline:

8. Does the bag bounce so much that marching up an incline becomes difficult? _ yes N _ no

9. When going uphill what aspects of the pack hamper movement?
- **general response was "none", one response of "weight shifting"**

10. Does the pack affect your stability or balance when going uphill? Explain.
- **general response was "no"**

C) Marching down an incline:

11. Does the bag bounce so much that marching down an incline becomes difficult? _ yes N _ no

12. When going down hill what aspects of the pack hamper movement?

13. Does the pack affect your stability or balance when going downhill?
- **only if grade is steep**

D) Cross-Country Skiing:

14. How often do you cross-country ski while wearing your rucksack?
15. In what ways does the pack make cross-country skiing more difficult?
16. How do you attach the skiis to the pack?

E) Snowshoeing:

17. How often do you wear snowshoes?

18. In what ways does the pack make snowshoeing difficult?

19. How do you attach snowshoes to the pack?
    - **bungy cords, sliding tails into slots behind pockets**

F) General:

20. How often do you walk sideways along a slope?
    - **not often**

21. In what ways does the pack make this difficult?

22. Are there any other activities you feel are important to consider when designing a pack?

    - **prefer the airborne style of ruck, more comfortable**
    - **more access to pockets, pockets sealable, waterproof**
    - **want to attach webbing better to outside of ruck**
    - **shorter people find this ruck hits their bottom, making it hard to walk**

G) Battle Order

23. Does the webbing have sufficient points of adjustment for you to make it fit to your body size and shape?
    Y _ yes _ no

24. Where are more adjustments needed?

    - **shoulder straps, if person has short upper body, the strap buckles dig into chest**
    - **more on waist belt**
    - **get rid of straps, waist belt only with magazine carriers and water**

25. a) Do components of the webbing system fail?
Y _ yes _ no

b) If yes, check all that apply.
_ straps
_ rivets
Y _ grommets
_ fabric tearing
_ seams tearing
_ buckles
_ other____

- **grommets/clips fail, fall off**

26. Which components have flexibility in their position on the webbing and where are they attached?
- **no flexibility**

27. Which components have fixed positions, and where are they located?
- **all components have fixed positions**

28. Which components are hardest to reach and where are they located?
- **water bottle, knife, bayonet, rain suit in the butt pack**

29. a) Do you ever wear the fragmentation vest with the webbing? Y _ yes _ no
- **in Rwanda, all day, everyone, (note: all seem to feel frag vest will become required for most)**

b) If yes, approximately what percentage of the time do you wear them together?
- **all time in active theatres**

c) Can the fragmentation vest be worn in place of the webbing? _ yes N _ no
- **not really but some try, filling pockets on vest, they hook components onto the flak jacket belt**

d) What are the problems associated with wearing the two together?
- **neck of flak vest pushes helmet over eyes, (note: Netherlands vest has a higher but larger diameter neck which should allow more neck movement)**
- **grabbing things from pockets awkward**

30. Do the webbing straps have sufficient padding?
Y _ yes _ no

31. Are the webbing straps:
_ too wide? _ too narrow? Y _ just right?

32. Do the webbing straps cut off circulation to the arms?
Y _ never _ occasionally _ sometimes _ always

33. Are the webbing straps around the neck area:
_ too close to the neck _ too far apart on the shoulders Y _ just right.

34. Do you find yourself shifting the weight of the webbing around regularly? _ yes N _ no

QUESTIONNAIRE #2 AND RESPONSES

35. Would you rather have one large compartment on the interior of the bag, as you have now, or several compartments?

    _ One large compartment.   _ Several compartments.

    - **outside pockets great**
    - **one large compartment better**
    - **most agreed on one large compartment**

36. Would you like more outside pockets?   Y _ yes   _ no

37. How would you alter the size and positioning of the existing pockets?
    - **larger size same positioning**
    - **most wanted the outside pockets to be bigger**
    - **they liked the outside pockets for finding stuff in a hurry**
    - **when ruck is full the pockets are too small. (rations don't fit in designated pocket)**

38. Would detachable outside compartments be useful?   _ yes   _ no
    - **yes on the flack jacket or on a load carrying vest**

39. Does the pack have sufficient points of adjustment for you to make it fit to your body size and shape?

    _ yes   _ no

    - **no, the buckles are a no-go**
    - **one thought there were too many straps and things hanging off**
    - **generally they thought there were (maybe options are not known)**
    - **load stabilizer strap is useless**
    - **any adjustments have to be made on the fly (they have no time to stop and adjust)**
    - **weight rides too low**

40. Where are more adjustments needed?

    - **waist belt, shoulder straps need work**
    - **waist belt is not used by some if the frame is too short (no adjustments in frame length)**

41. How much would you estimate your pack to weigh (on average) when loaded?

    Summer: _ 40-60lbs   Winter: _ 61-80lbs   _ 81-100lbs   _ 101-120lbs

42. a) What approximately is the maximum weight carried in the pack?

    _ 41-60lbs   _ 61-80lbs   *_ 81-100lbs   _ 101-120lbs   _ more___________

    b) What activity were you engaged in while carrying the maximum weight?
    - **marching, snowshoeing, not combat**

    c) How long was this activity?
    - **16 km, less than 2.5 hours to qualify. (BET Qualification run)**

43. Do the straps on the pack have sufficient padding while wearing:
    _ a T-shirt
    _ a light jacket
    _ a fragmentation vest
    _ a winter jacket

    - **most thought the padding was sufficient**
    - **one thought there wasn't enough while wearing a T-Shirt**
    - **when load stabilizers were used by one person the shoulder straps bunched up causing blistering**

44. What effect does wearing the fragmentation vest have on the pressure points of the pack?
    - **distributes the load**

45. Are the straps: _ too wide? _ too narrow? _ just right?

    - **one wanted them thicker not wider**
    - **one didn't want the ends of the straps doubled over and sewn; this makes it hard to feed through the clips**

46. Do the straps cut off circulation to the arms? _ never _ occasionally _ often _ always
    - **see question #2 on the written answer sheet**

47. Are the straps around the neck area:
    _ too close to the neck _ too far apart on the shoulders _ just right
    - **see question #3 on the written answer sheet**

48. a) If there was a sternum strap, would you use it? _ yes _ no
    b) Why or why not?
    - almost everyone said yes
    - reduced the tendency of straps to slip off
    - relieved shoulders

49. Have you had any short term injuries resulting from wearing the pack? (i.e. bruising, chafing, blistering, numbness in arms or fingers.)
    - **see question #6 on the written answer sheet**

50. Have you had any long term injuries from wearing the pack? (Example: rucksack palsy, pulled muscles) If yes, please detail.
    - **see question #7 on the written answer sheet**

51. Of packs from other countries or commercial packs that you have seen, please give some features that you would like to see on your pack.
    - **never seen it**
    - **the valise was better at the top (mostly a weight issue and it didn't bump on your bum)**

52. How important is it to be able to twist your back (hips one way and shoulders the other)?
    - **a lot thought it was very or somewhat important**
    - **due to training they needed manoeuvrability**

53. How important is it to be able to lean forward?
  - **very important**
  - **helmet interferes with pack**
  - **this is the most important of the three motions**

54. How important is it to be able to lean to the side?
  - **same as #52**

55. Where do you like to carry the load and does it vary for any of the following activities?

Walking on level ground:	Hips:__________	Shoulders:________________
Walking up hill:	Hips:__________	Shoulders:________________
Walking downhill:	Hips:__________	Shoulders:________________
Walking along a slope:	Hips:__________	Shoulders:________________
Boulder Hopping:	Hips:__________	Shoulders:________________
Running:	Hips:__________	Shoulders:________________

  - **more or less all on shoulders**
  - **a 50/50 split would be great...**
  - **they would like to be able to shift the weight from shoulders to hip and back on the move**

56. Are there any other comments you would like to make concerning topics you feel we have no covered sufficiently? Elaborate on any features of the current load carriage system that you like or dislike.

  - **webbing and rucksack do not work together**
  - **webbing is usually thrown over the top of the rucksack**
  - **investigate a load carrying vest**

QUESTIONNAIRE #3 AND RESPONSES

MARCHING ORDER

57. a) Has your frame ever bent or broken? _ yes _ no

b) If yes, to what extent?

- **yes, the wires break**
- **the frame bends**
- **frame warps**
- **one person out of 8 said yes**
- **airborne use old frame; present ones crack\break**

58. Would you prefer a more flexible frame that would contour more to the shape of your back?
Y _ yes _ no

- **most responded yes**
- **commercial frames nice, not strong enough**
- **likes the British Bergen pack (cap. 200 lb); Canadian ruck not close**

59. Is your pack typically full or does the volume of its contents vary a lot? Y _ full _ varies

- **varies in weight**
- **usually full, contents vary**

60. a) Do you use the compression straps?
_ yes _ no _ sometimes

- **what are they??**
- **straps come loose and the load shifts around**
- **they use tape to secure the compression straps (tape no good in winter though)**

b) If yes, which ones?

61. Are there enough compression straps in the pack to ensure the smallest loads you carry are not moving inside the pack?
Y _ yes N _ no

- **no, the load still shifts around**

62. Do attachments to your pack (ex. sleeping bag) stay in position? Explain.

- **No, we use heavy duty metal clips on the strapping to hold the valise; this makes the straps fray**

63. What do you normally put in your valise?

- **enough to set up a shelter: sleeping bag, ground sheet, bivi bag, shaving kit, wash basin**
- **ground sheet, 2 layers sleeping bag, bivi bag, sleeping bag liner, ranger blanket**
- **air mattress, washbasin, shave kit**

64. Has your pack ever caused you to loose your balance? If yes, why?

65. a) What features do you consider absolutely essential in an all purpose rucksack?
    b) Are there any features that are necessary for your particular trade?

66. If you could make one single improvement to the rucksack you have what would it be?

67. What features of the existing rucksack do you find creates problems for you? Why?

68. Could you accept the idea of a two part pack? (i.e. a frame plus one or more detachable soft packs, similar the U.S. ALICE pack.)

- **good idea**
- **most people thought it was a good idea but a couple said no**

69. While marching with both the webbing and the rucksack, where do you normally wear the webbing? If you attach it to your pack how do you attach it?

- **some attach it to the rucksack the way it would be attached to their body (webbing shoulder straps and waist straps around the rucksack)**
- **others thought this was a very bad idea however because when the ruck had to be taken off in a hurry the webbing came off too. This put others in jeopardy as well as the person wearing the pack**
- **taller people can't wear them together because the straps on the webbing won't allow them to place the webbing low, below the ruck**
- **others thought it could be worn better on taller people because they have more space laterally to put everything**
- **some just hang the webbing over the pack without it being tied in place**
- **the but pack has to be removed from the webbing when the rucksack is put on**

70. While wearing the webbing and the rucksack, do the two sets of straps interfere with each other or movement? If yes, please comment.

- **not a really big problem**
- **most think the webbing should be replaced with a load carrying vest**

APPENDIX 7.3 Report on the Civilian Backpacker Focus Group

7.3.1 Introduction:

A focus group of eight experienced civilian backpackers was interviewed on January 18, 1995. They examined the Canadian 1982 large field pack, the U.K. internal frame short back rucksack, the U.S. medium field pack and LC1 frame and a commercial expedition pack. The procedure for the focus group was as follows:

1) A brief explanation of the objectives of the APLCS project was given.
2) Participants examined and donned the packs. They were asked for their comments on each pack immediately after their examinations. A summary of these appears in Section 7.3.4.
3) A group discussion was then conducted following a prepared list of questions. These discussions are reported in Section 7.3.2.
4) Finally, individuals were asked to fill in a questionnaire. This was to determine their individual methods for dealing with stability, balance, and load distribution issues. The results of the questionnaire are reported in Section 7.3.3.

7.3.2 Civilian Expert Trekker Comments - Summary of Group Discussions:

QUESTION: WHAT MAKES A GOOD LOAD CARRIAGE SYSTEM?

Discussion: **PACK FACTORS**

Packs are often specific to a task. For example for skiing and climbing, it is better if the pack is narrow to improve balance and to minimize the restriction of arm movement.

Lumbar supports are important for comfort; they help distribute the load and support the lower back.

The pack must allow adjustment to the shoulder and hip belts to allow the user to change the distribution of the weight. It is important to be able to shift the load between the hips and the shoulders in response to the terrain and fatigue.

It is hard to repair straps if they are attached directly to the fabric of the pack because the cloth is destroyed. Field repairs are much easier on straps that can be completely removed or are directly attached to a frame (external frame packs).

Zippers are OK if they have a strong grab string attached. They are often hard to repair.

Cordura bad in the snow.

FASTEX C clip is faster to do up on hip strap.

Discussion **LOAD FACTORS**

Always very inconvenient to change the load distribution while underway because it requires the user to unpack and repack.

There was a difference of opinion on the most desirable location of the load centre of gravity (C. of G.). Most indicated a range from mid-back to high back. Low on the back was not considered desirable by any or the participants.

(a) Not confirmed but women may tend to prefer the C. of G. somewhat lower than men do.

(b) There may be a difference depending on whether the pack is an internal or an external frame pack. Users indicated that they may prefer the weight to be carried somewhat higher in an external pack.

Group opinion was that there is a greater energy cost with the load carried high.

People had trouble assessing how much weight should be carried on the hips. The suggested value ranged from 60 to 80% of the load and varied with the terrain being traversed.

Discussion **SITES OF DISCOMFORT**

Moderate to severe bruising on the hips above the anterior superior iliac spine. Thought to be more prevalent for women.

Note: review of the geometry of the iliac crest in the male and female indicates this area comes to a sharper, more horizontal point in the female.

The back and top of the shoulders.

Increasing load tend to cause pressure induced sores on the hips.

Discussion **STRATEGIES TO REDUCE DISCOMFORT**

Put lots of weight on the hips when in transit (i.e., marching).

When the hips require a rest - move the weight onto the shoulder straps. It is also possible to loosen the shoulder straps way off and let the hip belt act as a hinge the person and the pack. This shifts the location of the forces acting on the body to relieve the tired muscle groups.

Discussion **STABILITY**

It is important to be able to adjust the pack on the move so the load can be carried in a position which is the best compromise between the mobility and stability demands of the activity.

Discussion **LOAD CONTROL AND SAFETY**

On smooth terrain, shoulder straps are loosened off and load control was described as " loose".
On rough terrain (i.e. rocks) all straps were tightened and the load is carried tight and close to the body.
On unstable footing, trekkers take smaller steps and keep the load tighter for balance.
If going down in a fall, try to rotate onto back and allow the pack to break the fall.
In deep water or crossing deep water, take the pack off altogether.

7.3.3 Summary of Questionnaire Responses

Participants were asked to fill in a short questionnaire to determine their individual methods for dealing with stability, balance, and load distribution issues.

1. Walking on level ground, what features of a pack help you to maintain your balance?

   - Sternum strap, good waist belt
   - Adjustable so it fits my height
   - No parts which move independently (i.e. things lashed on to the outside that move freely)
   - Weight on the hip belt
   - No heavy items dangling
   - Weight evenly distributed in pack, not top or bottom heavy
   - A light pack!
   - Tight and close
   - Secure feeling with comfortable fitting pack

2. Walking on level ground, where would you like the centre of gravity of the load?

   - Half way down the back
   - At shoulder level
   - Not at the top, below my shoulders
   - As close as possible to my own centre of mass

3. Boulder hopping, what features of a pack help you to maintain your balance?

   - Sternum strap, good waist belt
   - Fits close to the body, no free moving attachments
   - Narrow enough so there is free movement of the arms
   - Adjustability, shoulder needs to be snugged up to keep pack close to body
   - Need to keep pack tight and close, don't want pack swinging after you've landed
   - Very tight fit, the more the pack acts with the body the better
   - Absolutely no independent vertical movement of the pack

4. Boulder hopping, where would you like the centre of gravity of the load?

   - Half way down the back, middle of back, just below my shoulders - Shoulder height
   - Low on back
   - Low

5. Going downhill, what features of a pack help you to maintain your balance?

   - Sternum strap, good waist belt
   - Fits close to the body, no free moving attachments
   - Narrow enough so there is free movement of the arms
   - Need easy shoulder and hip belt adjustment
   - Arms need to be free if using ice-axe
   - Minimal vertical pack movement

6. Going downhill, where would you like the centre of gravity of the load?

   - Half way down the back, middle of back, just below my shoulders
   - Shoulder level
   - Low on back
   - Low, a high C. of G. causes you to fall forward

7. Going up a steep incline, what features of a pack help you to maintain your balance?

   - Short enough at top so I can raise my head
   - Pack can't extend too far up, causes a too high C. of G.
   - Short fat pack easier to go up a steep hill with

8. Going up a steep incline, where would you like the centre of gravity of the load?

   - Half way down the back, middle of back, just below my shoulders
   - Shoulder level
   - Low, a high C. of G. would push you into the hill if you slipped
   - Low and farther away from the body to help you keep an upright posture

9. Along the side of a hill, (traversing), what features of a pack help you to maintain your balance?

   - Sternum strap, good waist belt
   - Fits close to the body, no free moving attachments
   - Need pockets so no hindrances tied on, important to be balanced side to side
   - Should move with the body

10. Along the side of a hill, (traversing), where would you like the centre of gravity of the load?

    - Half way down the back, middle of back, just below my shoulders
    - Shoulder level
    - Low on back, I guess I generally have it somewhere below my shoulders and above my waist
    - Low, where it is easier to control with my legs. A high centre of mass would require the upper body to do most of the stabilizing

11. How important is it to be able to twist your back (hips rotate one way, shoulders the other)?

    Not Important Somewhat Important Very Important
    0---I---100

    Responses varied from approximately 40 to 90%, Average = 65%

12. How important is it to be able to lean forward?

    Not Important Somewhat Important Very Important
    0---I---100

    Responses varied from approximately 40 to 90%, Average = 58%

13. How important is it to be able to lean side to side?

Not Important	Somewhat Important	Very Important
0--	I--	100

Responses varied from approximately 45 to 80%, Average = 65%

14. Where do you like to carry the load? Please give a percentage breakdown. (Average values are shown.)

Walking on level ground:	Hips:75%	Shoulders:25%	Range: Hip 50-90%
Walking uphill:	Hips:75%	Shoulders:25%	Range: Hip 60-90%
Walking downhill:	Hips:72%	Shoulders:28%	Range: Hip 50-80%
Walking along a slope:	Hips:67%	Shoulders:33%	Range: Hip 50-80%
Boulder hopping:	Hips:65%	Shoulders:35%	Range: Hip 50-80%
Running:	Hips:67%	Shoulders:33%	Range: Hip 60-80%

15. Where do you feel the first significant discomfort and what causes this?

- Sore hips, causes by heavy loading in this area
- Hips first, then shoulders, sometimes knees and legs
- Shoulders, then knees. I would like to carry all weight on my hips and only use shoulders to stabilize the load.
- I put as much weight as possible on my hips but i almost always feel it in the shoulders first.
- "Hip pointers", i.e. bruising on the hips
- Very heavy load, shoulders and knees
- Two parts to the shoulder discomfort; shoulder pain due strap pressure on top of shoulder, and strain in upper back muscles. Sternum strap helps this.

16. Other comments on what makes a good pack?

- Needs to be easy to repair in the field
- Lots of pockets to organize kit, pockets shouldn't flop around though
- Not all one big bag, 2 major compartments
- No zipper closures which would have any stress on them, can't close easily
- The fewer zippers and gadgets the better, fewer things to break
- Need good padding on hips and shoulders
- Tough, should feel like it will never break on you
- Heavy duty buckles and zippers
- Easy access to all areas of pack
- At least water resistant, water-proof highly desirable
- Needs to be adjustable to size of torso, shoulders and hips

7.3.4 Civilian Expert Trekker Comments on Military and Civilian Packs

a) CANADIAN - 1984 Pattern Large Field Pack, pack only no webbing

POSITIVE

lower part of frame helps for comfort
side to side stability "pretty good"
felt comfortable on body with 15 kg load
lots of pockets
map pocket is useful
buckles don't unwind but take a long time to wind up

NEGATIVE

accessibility of straps when putting on (hard to find) tightening straps needed on both sides of hips (lacks hip stabilizing straps) velcro gets dirty and wet then doesn't attach properly hip strap has no padding,
hip strap tends to get tangled up
pack is too wide for arm swinging
"shoulder to ear" straps are difficult to adjust on the move, they are put on backwards.
lower part of pack tends to dig into butt after wearing for a while
can't stand pack up
no way to bring pack C. of G. lower so pack is top heavy
not enough padding on metal frame
not designed for ease of adjustment on the fly
need adjustment for hip to shoulder length
need adjustments for length of shoulder straps to move load up or down
lacks a sternum strap
shoulder-ear strap too far back for ease of use

b) UK Internal Frame Short Back Rucksack - Pack only, no webbing

POSITIVE

good shoulder strap location
good direction of pull on shoulder-ear strap
high load stability because weight up on shoulders
good feel sitting on back
liked UK better than US because weight higher on back

NEGATIVE

not adjustable for person height (support bars)
all weight high on shoulders
anatomical shape of bars are not one size fits all; are there different sizes?
hip strap does not work and doesn't look like it was even for that purpose
needs sternum strap
hip belt sits on bottom of ribs cage, would restrict breathing if pulled tight

c) U.S. Medium Field Pack with LC-1 Frame, pack only no webbing

POSITIVE

ventilation good
has nice side pockets
able to attach things to frame
metal buckles are strong
bottom clip on the shoulder strap works well

NEGATIVE

cannot distribute weight onto hips because hinge prevents it
greater lever arm so must lean far forward to compensate for this fact
cuts into shoulders
difficult to adjust shoulder strap length
shoulder to ear strap backwards so cannot adjust on the move
should have padding all around hip belt
weight cannot be transferred to hip belt because it is detached by a hinge arrangement
hip belt buckle is plastic
not enough padding on shoulder straps

d) COMMERCIAL PACK - GREGORY DRU
Gregory Mountain Products
100 Calle Cortez, Temecula, CA 92590

POSITIVE

padding at lower back supports weight comfortably
strap across chest increases stability
stiff hip belt takes weight well and is easy to get into
elaborate compression straps can stabilize load
top comes off for use as fanny pack, which can be handy
ice axe loops and attachment points are useful

NEGATIVE

strap across chest can restrict breathing when pulled tight enough to be useful
frame doesn't seem to come out of pack - normally internal supports can be shaped ed to individuals back
(MANUFACTURER CLAIMS THESE SELF- MOULD)
can shoulder straps be adjusted to different heights? (YES)
large number of straps could get tangled in trees

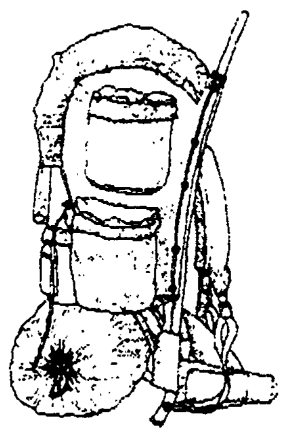
APPENDIX 7.4 Load Carriage Backgrounder Report

Dr. Jim Raffan, from the Faculty of Education, Queen's University, is an experienced outdoorsman and trekker. Furthermore, he has conducted field trials on commercial equipment at the Queen's outdoor facility. He has prepared a backgrounder report on Load Carriage Systems for the Ergonomics Research Group.

Ediron Services

Load Carriage

Backgrounder



A report and presentation prepared for the
Ergonomics Research Group
Queen's University, October 28, 1994

James Raffan, PhD

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Introduction

As Project Leaders in the Advanced Personal Load Carriage System subgroup of the Queen's University Ergonomics Research Group begin deliberations on the development of a new personal load carriage system for the Canadian Forces, there is an immediate need for background on commercial load carriage products and the status of current industry research as exemplified by packs for sale in the contemporary retail market place. This background report is intended to accompany an oral presentation by Mark Coté[1]. The purpose of this report and presentation is to provide APLCS Project Leaders with a general introduction to civilian load carriage traditions and equipment, and to respond to the following questions posed by the research group:

a) What are the items to look for in a good load carriage system?
b) How should present commercial load carriage systems be worn?
c) How important is individual fit and function?
d) How important is clothing worn under the pack to fit and function?
e) How important are load and load distribution to fit and function?
f) How varied are individuals in deciding their personal load distribution?

Presentation: Queen's University Faculty Club, Friday, October 28th, 1994

3:00	**Mark Coté**--Formal Presentation & Demonstration
4:00	Informal Try-outs, Questions and Answers
5:00	Discussion
5:30	Conclusion of Presentation

Load Carriage Designs Available for Demonstration and Try-out:

A) Tump strap--Woods #1 Canoe Pack
B) Plain Rucksack--Duluth Pack
C) Original Bergan's Pack from Norway
D) Original Kelty Contoured External Frame Pack
E) Early Internal Frame Packs
F) Outbound Internal Frame Pack
G) Early U.S. Military Pack with triangular metal external frame
H) Maine Black Ash Pack Basket
I) Kanuk 80-litre Expedition Pack
J) Lowe "Cloudwalker" Internal Frame Pack
K) Lowe "Expedition" Pack Internal Frame Pack
L) Waterproof "Blag Bag" by Phoenix
M) Tilley Multi-Pocket GoreTex Vest
N) Black Feather Waterproof "Barrel" Pack
O) Camp Trails Convertible Fanny Pack

[1] Biographical details appended.

The Evolution of Load Carriage

Tumpline: Adapted from the simplest aboriginal carrying method, the tumpline is simply a long leather strap used to tie up and carry a load. The strap is usually about 6 m long, with a broader (5 cm) headpiece in the middle that is used to hang a load from the forehead. Tumplines were used very effectively with large loads over long distances, for a long period of time, by many cultures around the world. When used properly they can position a load over the feet of the wearer with only a minimum of bending, but the design does substantially compress the spine during transit. Unfortunately there is a lot of technique involved in the use of this load carriage design, and as a result anyone who tries it in contemporary times, without the know-how, finds it highly unsatisfactory.

Tump Variations: A variation on the tumpline for load carrying was a simple basket made of strips of wood from the black ash tree. Made in the Micmac tradition from New Brunswick to Maine, these were carried by means of a tump strap alone or with a combination of shoulder straps and a tump. Another variation of the tumpline design is the "wanigan" or "wangan box," an Algonkian term used to describe a wooden box carried with tump alone.

Frameless Rucksack: This is a simple sack hung on the shoulders with two straps. There were two significant problems with this design when it came to carrying larger loads: 1) the load tends to bulge out at the bottom of the pack forcing the wearer to lean forward to balance the load and to tire quickly; 2) with the load directly on the back there is little ventilation, resulting in heat build up and perspiration between pack and carrier.

Canoe Pack (also called "Duluth" or "Woods Pack"): This is really just a large canvas or nylon sack with shoulder straps and a tump strap (optional) that packs easily in a canoe but is far from ideal for extended distances. One of the great advantages of this load carriage design is that the packs themselves can be packed and loaded in aeroplanes, boats, trucks and trains with a minimum of fuss or breakage.

Trapper Nelson (also called "Yukon"): This is a straight wooden frame with wrap-around canvas suspension system that distributed the load evenly over the whole back. It was a boon to people who needed to carry different types of loads; from moose quarters, to outboard motors, or plain ruck sacks, anything could be lashed on. With the canvas material fitting snugly down the whole length of the back these packs tend to be very hot to wear. From an engineering standpoint, the Trapper Nelson pack design demonstrated that supporting the load from the sides of the pack was inferior and much less efficient that supporting it from the top edge. A bar across the top of the Trapper Nelson, to which can be affixed the shoulder straps, is an important innovation to this design. Later version of this design were also called the "Army Packboard."

Frame Rucksack (also called "Bergans-type"): The Bergans Pack Company of Norway made major improvements in rucksack design by adding a triangular metal frame and by making a sack with a narrow bottom and wide top. The frame stiffened the load and facilitated a transfer of some of the weight of the pack onto the waist. The combination of the stiffer pack and the narrow bottom/wider top sack also allowed the centre of gravity of the pack to be moved upward. This design required a smaller forward lean by the wearer to put the pack's centre of gravity over the feet. The frame also allowed minimal ventilation between pack and wearer and to some extent prevented irregular shaped objects from sticking into the back of the wearer. Although the frame transferred some of the weight onto the large muscles of the legs, the Bergans-type design still puts most of the weight onto one's shoulders and can impose fierce vertical pressure on the spine in addition to heavy strain on the shoulders, neck and back, all of which hastens fatigue. Also, depending on how this pack is loaded, the frame can concentrate weight in the small of the back instead of on the hips, a situation that rapidly leads to fatigue and pain.

Contour Frame Pack (also called "External Frame"): A.I. Kelty, of California, took the frame idea one step further by constructing an S-shaped tubular aluminium frame that followed the contours of the back. The contoured frame brought the load closer to the back, and in early designs allowed the pack to be made longer, reaching below the waist of the wearer, and narrower which allowed the load volume to be maintained (compared to the earlier rucksack designs). Additional height on this design allowed the centre of gravity of the pack to be placed over the feet with only a very slight forward lean. The pack was generally attached to the frame with clevis pins secured with wire rings. The frame and pack actually sat on the back of the wearer via a rudimentary suspension system involving nylon or canvas straps, made taut between the side bars of the frame.

The most important innovation of the Kelty pack was the addition of a waist belt (also called "belly band" or "hip belt") that transferred most or all of the pack weight onto the hips. The boon of the waist belt was this transfer of weight onto the large muscles of the legs which, Kelty maintained, are well suited to carrying a lot of weight without special training. Like the Trapper Nelson, the external frame pack is versatile and can be adapted to carry almost anything from fuel cans to young children in harness. The disadvantages of this design include problems with stability of the wearer when walking in uneven terrain because of the high centre of gravity; there can also be problems with looking up because of the the frame impeding rearward tilting of the head, and problems with the frame catching on surrounding rock or vegetation.

Internal Frame Pack: The internal frame pack attempts to maintain the structural advantages of the external frame pack while at the same time trying to circumvent the disadvantages of awkwardness. Internal frame packs are stiffened by the addition of "stays" made from plywood, fibreglass, metal or composition materials that, as contoured sheets or rods sit inside sleeves sewn into the inside of the back of the pack. These are attached to the top of the yoke and to the bottom of the pack straps, and to the waist belt. If the stays are in rod form, they are used vertically or in an X-configuration. And in some cases, the stays can be removed and adjusted by bending to match the shape of the wearer. Although the solid plastic, wood, or fibreglass internal frame will not stop the pack from resting right on the back of the wearer and causing heat build-up, it will stop irregular shaped objects from poking the wearer in the back during transit. One might think of the internal frame pack design as a compromise between the external frame pack and the frameless rucksack. This design brings the pack closer to the body than an external frame, making it less cumbersome, while still allowing some transfer of weight to the hips. Typically internal frame packs are used by active outdoors people such as climbers and skiers.

Pack Innovations: Nowadays there are excellent internal and external frame packs, although it would seem that the improvements in design and versatility of the internal frame pack have given it the edge in the pack market. There have been, however, significant innovations in all aspects of pack design. Perhaps as important and significant as Kelty's addition of the waist belt was the development by Lowe Alpine Systems of a much improved complete and integrated suspension system for backpacks. Using a complicated series of straps and pieces of nylon webbing, the Lowe Pack Company was able to suspend a load on the straps of the wearer and allow for all manner of individual differences in body size, shape and personal fit preferences, and to do so without compromising--occasionally even increasing--pack efficiency. In fact, the Lowe suspension system became (and remains) the foundation and standard on which all future manufacturing design and innovation has occurred. Over the years, Lowe, and others, have made other substantial innovations with the ways in which packs are designed and configured--the addition of adjustable/collapsible top closing flaps, contoured shoulder straps, compression straps, and stabilizers on waist and shoulder straps are examples--but, while significant, none of these has been close to the design leaps made by Bergans with the frame, Kelty with the waist belt, and Lowe with the personal suspension system. Product differentiation in the pack market over the last decade or so, since the advent of the Lowe suspension system, has not been so much on the basis of function and efficiency as it has been on aesthetics (colours and choices of materials and fastening appointments) and "sex appeal" (meaning bells, whistles, buckles, map pockets, avalanche recognition devices, fancy fabrics, space age stiffeners, etc.). While there is a very small, but robust, cadre of designers in North American and around the world making load carriage innovations on an almost daily basis, the improvements they are making are much more subtle with respect to efficiency and performance than were the changes that occurred in the days of Kelty and Lowe.

Perhaps worthy of special mention is a relatively recent pack design innovation by Kanuk Inc. of Montreal who introduced a roto-moulded, semi-rigid plastic back on two sizes of packs (65 & 80 litre). This design was revolutionary in the sense that it had the rigidity of an external frame and all the versatility and advantages of an internal frame pack. Another innovation by Kanuk on this pack was the addition of a full front zipper on a top-loading pack that would allow entry to the pack at the top, bottom or middle of the load. Unfortunately this pack was priced beyond the highest end elite packs and never really took off as a item for even the most affluent backpackers.

Current Pack Manufacturers

Camp Trails--*Canadian Distributor*: Johnson Worldwide Associates Canada Inc. 4180 Harvester Road, Burlington, Ontario, L7L 6B6 (905) 634-0023 Fax (905) 634-0261 (American Parent in Phoenix, Arizona)

Coast Mountain Sports--(Vancouver)

Dana Designs--(USA)

Gregory Packs--(USA)

Kelty Company--(Glendale, California)

Lowe Alpine Systems--*Canadian Distributor*: DAYMEN Outdoor Marketing Ltd. #22 3241 Kennedy Road, Scarborough, Ontario M1V 2J9 (416) 298-9644 FAX (416) 298-3553 **Head office:** P.O. Box 1449, Broomfield Colorado, (303)465-3706 FAX (303) 465-3301

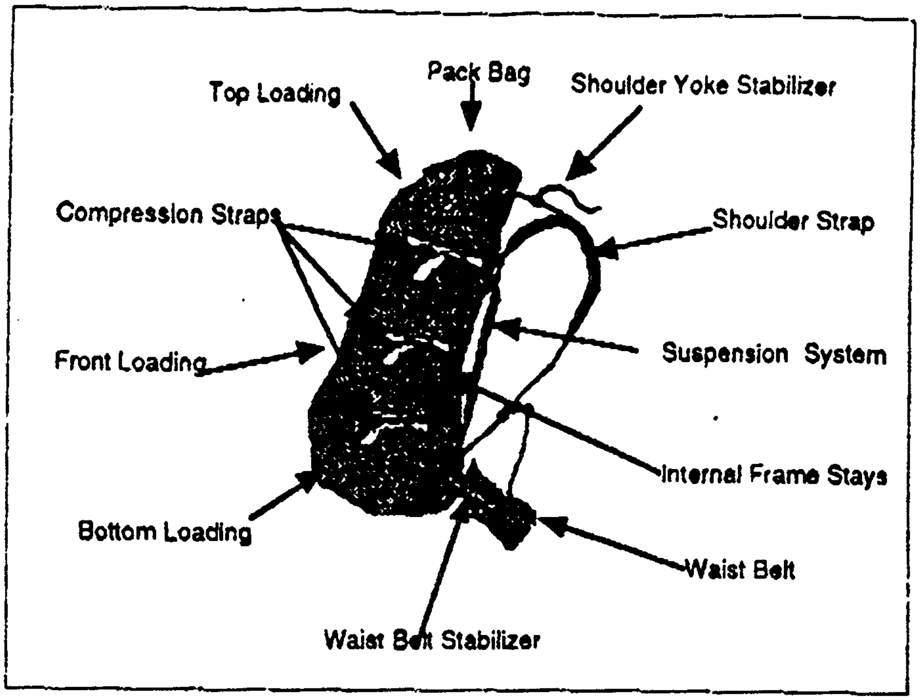
Madden Packs--(USA)

Mountain Equipment Co-op--(Canada)

North Face--*Canadian Distributor*: In-Sport Fashion Inc. 9445 Jean Pratt, #301, Montreal, Quebec (514) 385-1577 Fax 385-9940 **Head Office:** 1111 8th Street, Berkeley, California, 94710

Outbound (Division of Taymor Industries Ltd.)--*Canadian Office*: 205 Limestone Cresc., Downsview, Ontario M3J 2R1 1-800-387-3512 FAX (416) 736-0401

Anatomy of a typical Load Carriage Device



Pack Features

Centre of Gravity: For a load to be carried efficiently, the wearer should be as close as possible to normal straight standing posture. Much effort is expended when a wearer walks while bending forward at the waist to compensate for a load carried low on the back. According to Hatton (1992) "the heaviest items in the pack should be as close as possible to an imaginary straight line running down through the body from the head to the feet, and as high as possible." For walking on flat terrain, ideally the centre of gravity of the pack should be above the centre of gravity of the wearer and on or close to the imaginary line between head and feet; however, this loading and configuration of the pack can create balance problems with unskilled wearers or in uneven terrain. Most backpacking guides suggest that balance is the key, with weight to the top a favoured load configuration--but, you don't want heavy items so high on a frame that they tip the wearer forward, nor does one want load so low and far away from the body that the wearer is pulled backward. Under ideal conditions, the suspension system and the load should be adjusted to the terrain and the kind of activity in which the pack and wearer are engaged: weight high for flat, easily-travelled terrain; weight slightly lower and near the middle of the back for greater balance in rougher terrain; and weight low on the back to lower the body's centre of gravity for boulder hopping, river crossing and related activities. The National Outdoor Leadership School has a simple packing system that might be useful (or something like it) to pass along with user notes on a new design. Although an object like a pack has a centre of gravity, when thinking about on object like that attached to a person, it is easiest from the wearer's point of view to think of the pack and the person as one, the size shape and configuration of the pack simply as a force that moves the wearer's centre of gravity. From a testing and design perspective, it may be of more use to keep the physics of the pack and the wearer separate for purposes of analysis.

Fit: The waist belt's role is to transfer weight from the pack onto the hips--it does the "carrying," without undue compression of the spine. Likewise, it is useful to think of the shoulder straps as taking some of the weight (as preferred by the wearer) but as having the primary purpose of ensuring balance of the wearer when walking with a load. The shoulder straps should come up over the shoulder and drop slightly to one attachment point in the centre of the pack. The waist belt should fit snugly around the iliac crests of the pelvis and transfer all of the pack weight (at least to begin) onto the wearer's hips. Besides the overall size, weight and volume of the pack, the critical adjustment to make in order to match the size of the wearer to size of the pack is the distance between the shoulder strap attachment point and the waist belt. On most "better" commercial packs, the waist belt location on the pack is fixed but the insertion point of the shoulder straps can be adjusted over a large range of sizes by virtue of a webbing ladder sewn into the back of the pack. This ladder rides underneath the webbing of the suspension system and, if the suspension system is adjusted correctly, is of no fit or comfort consequence to the wearer.

Pack Bag Design and Material: The place where most pack bags fail is in the stitching which tends to wear either on the frame or at places where the pack wears through being set down on rough surfaces. The next most common failure is in the zippers and closures which tend to suffer first from hard use. There is no doubt that the best closure material currently available is a plastic compound with the trade name Fastex. Most packs nowadays are made from heavy, waterproof nylon material; a popular brand name of this cloth is Cordura.

Spindrift Collar: Usually made of light nylon material, the spindrift collar is an inside, extendible high tube of material that cinches closed with a draw string on top-loading packs. This keeps packs weather tight and can assist in the carriage of bigger loads.

External Pockets: Attached or detachable, these ensure easy accessibility to smaller items in a carried load. They can however be the cause of imbalance in a load.

Side or Rear Zippers: On a top-loading pack, these offer access to items in the middle or the bottom of the load. They are handy, but can compromise the structural integrity of the pack and/or the weatherproofness of the unit.

External Frame Design and Material: Most pack frames are made of magnesium and/or aluminium, although new materials like graphite/epoxy and various other composite resin/fibre and plastics are being used. The key characteristic is light weight and high strength. Typically pack frames fail at the welds and joints. Some flexibility in the material can reduce stress on the welds but this must be done without compromising the all important stiffness which is critical to ensure efficient transfer of weight on the pelvic girdle. Fit is also critical with a pack frame. Some pack frames come in different sizes (usually determined by the distance between the top attachment point of the shoulder straps and the middle of the waist belt. On some pack frames the straps can be inserted at different points on the frame to accommodate different sizes of wearers. On other packs the frame itself can be adjusted to different sizes.

Suspension System: Nowadays all straps and horizontal webbing are made of nylon material, and on any one design of pack one can expect to find a wide range of strap sizes depending on the needs of the location. Wider straps tend to be spread out weight better than narrow straps (these are padded at the main weight-bearing locations at shoulder and waist), but narrow straps are lighter and work better for other purposes. It is in the straps and horizontal webbing that significant weight can be added or subtracted from a pack design--this aspect of the strapping is perhaps as important, or maybe more important the choice of pack bag and frame materials. Companies such as Lowe Alpine Systems have been experimenting with S-shaped contoured shoulder straps that add comfort to a pack.

Compression Straps: These are located usually on the sides of the pack bag and allow the pack to shrink to accommodate smaller loads; likewise, they can be used to bring a large load a little closer to the back of the wearer. Compression straps also reduce load shifting and as a result of that improve balance of the wearer.

Loading Adaptations: It is very difficult to put on a heavy pack. This can be aided by lifting straps on either side of the top of the pack bag. Lifting straps can also prevent or reduce seam damage caused by the application of lifting force in locations that are not fortified for this kind of force. This characteristic of packs also speaks of the instructions for use that can and should be part of every piece of equipment to ensure that it is used correctly.

Comfort and Utility Adaptations: These include innovations such as "office on the yoke" --a pocket to hold note book, pens, maps etc. that is attached to the front part of the shoulder strap on either or both sides of the

body. There are many adaptations like this on the current military packs, such as the flashlight holder on the yoke. What makes or breaks a design in the long run has to do with major design features like size, shape, and comfort, but it has also to do--and maybe moreso--with how useful the device is for the people doing the jobs required. Comfort and utility adaptations are critical to the success of any new design.

General Notes on Packs

Commercial retailers usually separate packs on the basis of function as opposed to design. For example, Trailhead, a central Canadian retail outdoor sports chain, tells their customers in a brochure that pack styles fit in four categories: expedition packs; travel packs; canoe packs; and day packs. In general the kind of load carriage equipment used by the military falls into the category of expedition packs (Aside: There might be virtue for the APLCS design team of thinking in terms of the innovations on commercial travel packs. Soldiers must travel to get to the fight. Adapting the design for travel purposes in the traditions of contemporary travel packs, such as the Lowe *Salida*, the Coast Mountain Sports *Radison*, or the Camp Trails *Frequent Flyer* might be an attractive attribute.) Trailhead also offers their customers the following chart:

Pack Size Guide:

Canoe Pack	90+ litres
Expedition	80+ litres
Backpacking	70 litres
Light Overnight	50 litres
Day Pack	30 litres
Boot Pack	20 litres
Side Pocket	8 litres

Alternate Load Carriage Options

Head Ring: This load carriage device is usually a straw or cotton ring with a diameter of about 15 centimetres on which the load is balanced on top of the head. Think about Asian and African women carrying huge jugs of water in this way. The tump strap is similar to the head ring, in the sense that the full weight of the load is carried on the head, but in the case of the head ring, the load is above the wearer's centre of gravity and directly in line with the spine and directly over the feet. The main drawback of this design of course is its attendant balance problems ... probably not the greatest thing with which to enter the fighting arena. There are, however, principles of load carriage that could come from an examination of this design.

Pulk: This is a small, usually fibreglass, slider (for winter use) attached to the bearer by means of two flexible wands affixed to either side of a waist belt. This load carriage device has been used by almost all major Arctic and Antarctic expeditions over the years. Extended travel without mechanical support has shown that groups travelling with gear *in tow* do much better than those with gear on their backs. Pound for pound, pulks, and devices like them are much more efficient on snow than backpacks.

Toboggan: The traditional winter load carriage device of the northern woods is a 3-4 metre Labrador style, narrow toboggan which is pulled with a 6 metre tump strap worn across the chest. In this pulling configuration, the arms are carried behind and wrapped a couple of turns in the side lines of the tump strap. This allows the arms to rest but also serves as a shock absorber to take up the differential stepping and resting power thrusts in the normal human walking gait. Precursor to the pulk, this too is a seasonally-specialized but highly efficient design for personal load carriage.

Web Belt: Carrying big loads on the waist belt is never a good idea, but as in the current web belt of the Canadian Forces, this belt with harness configuration can work well to balance some load carrying capacity with excellent speed and mobility. It may be that a new design could begin with this type of load carriage with some kind of fastener adaptation to allow the web belt and shoulder yoke to become the suspension system of a larger combination of pack bag and/or frame.

Vests and Pockets: The new Canadian Forces pocketed vest design that was being tested in Bosnia is very similar to the Tilley multi-pocket vest that is popular with photographers and journalists. Although it is difficult to carry large items with this kind of load carriage design, the weights that can be carried on the shoulders via the vest can be substantial. And, if the vest is carefully designed, accessibility of pocket contents is virtually assured without fuss or delay.

Universal Harness: Similar to the web belt idea, a new load carriage system may begin with a personally fitted universal harness, onto which could be attached all manner of loads and load carriage designs. The beauty of this design idea is that the universal harness could become the basis of a fully integrated, modular load carriage system that could be adapted with ease to all of the various needs and roles of current and future military personnel.

External Support: One cannot think in terms of load carriage in the military setting without acknowledging the importance of supporting vehicles and other platforms for load carriage. It may be that a future load carriage system should involve types of external support, not currently used in the military, that could carry the bulk of one unit's personal gear. This idea raises the problem of how you get the external support vehicle into all the necessary locations concurrently *with* the personnel, but nevertheless it may be an idea that is worth thinking about. If one goes ahead with the universal harness and modular load carriage system, the gear could be adapted to be carried with ease by the external support vehicle, or, for that matter, any vehicle used in the transport of military supplies and personnel (i.e. the same fastening system that is used to attach the pack bag to the universal harness on the soldier could be used to store the pack bag [instead of shelves] in the vehicles.)

Load Carriage Design Parameters

Once research is done with respect to the current and anticipated needs of the Canadian Forces for load carriage in the field, and once the APLCS Design Team has a thorough understanding of the shortcomings of existing and historical load carriage equipment, it will be time to begin the task of formulating a new and hopefully improved personal load carriage system design. At some point it may be of some use to create a mathematical and/or computer model of the personal load carriage mileau to explore possibilities and shortcomings in various new combinations of innovative design notions and re-applied existing ideas without the cost in time and money of prototyping and testing. And when the time comes for testing, there will need to be axes on which to make judgments about new design and how they perform. The following thoughts about design parameters are offered as first steps in that direction to add to existing thinking by the team.

Understanding of Need: Any design project is runs serious risk of misunderstanding and ultimately failure if there is not a clearly articulated understanding of need to drive all aspects of innovation. At the moment, there is no clear sense (at least in this corner) about what it is that the team is setting out to do. Items one and two of the mandate as outlined in Dr. Stevenson's memo of October 3, 1994 are clear enough, but before the team can move onto any deliberations and/or action on generating details and requirements for Concept 1 of a prototype, there needs to be a substantial amount of research done on need, clarifying for whom in the Canadian Forces new load carriage is required, and under what environmental conditions it will be used etc. etc. Of special importance is the matters of limits on the cost of the final production design. Like all aspects of setting objectives for the design process, this needs to be clarified sooner rather than later.

Philosophy of Design: From the outset, it seems necessary that decisions be made about whether the team is setting out to create a modular load carriage system that will integrate with any and all aspects of military operations in the field, or a more individualistic personal load carriage system that does not need to 'fit' in a design sense with other load carriage systems and mechanisms for the movement of supplies and materials. Likewise, it seems a necessary step to decide whether the team is setting out to create a load carriage system that will tailored to the needs of individual elements or roles (i.e. airborne troops) or whether it is in the business of creating more or less one design that will do for every need. Further, is the team setting out to design a very sophisticated load carriage system that will need much training and support to implement in the field, or is it setting out to create a new load carriage system that can be used without any instruction at all? These are big questions that could come to bear very substantially on how the design process proceeds.

Pack Bag Features:

Volume--overall size and weight capacity and number of compartments;

Shape--to fit required contents and to ensure efficient load placement;

Material--with appropriate "proofing" against water, temperature, fallout, abrasion, shrapnel. What will environmental conditions to the material on the long term (e.g. ultra-violet light)?

Access--how the contents will be accessed and how these points will be "proofed" as above;

Fasteners--what kind of buckles, straps and zippers, closures will be used, what about the noise that jangling zips and closures make?

Attachment System--how will the bag(s) be attached to the frame?

Pockets--detachable, attached, size, shape, material, transferable.

Frame Features:

Design--Internal frame, external frame, web belt modular, other?

Material--magnesium, aluminium, graphite/epoxy, availability, performance in expected field conditions (i.e. desert, arctic);

Shape--for maximum personal comfort and efficiency, for maximum ease in loading and transport when not being worn;

Weight--to maximize efficiency for individuals and for the job of shipping the gear en masse;

Flexibility/Durability--will it be able to withstand the rigours of military use over time?

Suspension System Features:

Design--can it be adjusted with equal efficiency to the full range of personnel sizes? Can it support all types and sizes of loads expected to be carried? How will it wear over time?

Straps--what material, how wide, UV resistant, placement, lengths, contoured?

Pads--is it in the right place, can it be adjusted to suit individual needs, will the material stand up under field conditions and over time?

Fasteners--what are the tolerances required of buckles, straps, and fasteners and will the chosen materials meet those requirements? Is there anything better than Fastex brand?

Notes

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As part of the research for the Advanced Personal Load Carriage System (APLCS) for the Canadian military, the Ergonomics Research Group (ERG) at Queen's University has performed an extensive review of current load carriage systems and load carriage literature. A background report on the evolution and current state of load carriage equipment was prepared for ERG. Civilian trekkers responded to interviews covering many design features and ergonomic preferences for current load carriage systems. They reviewed the three military and one commercial pack that ERG possesses. Military load carriage equipment from Canada and two foreign countries has been examined and evaluated by our team of scientists and load carriage experts. Canadian military personnel provided feedback through questionnaires and interviews on the strengths and weakness of various design elements. Additional information was solicited on load carriage limits, typical tasks and operating conditions. In some cases, there are clear deficiencies in some design elements. However, in many instances the success of a particular configuration is individual and/or task and/or environment specific. One of the main benefits of this review has been a better understanding of the interplay amongst these factors. Scientific and popular literature on load carriage design elements and performance ratings has been summarized in this report. Many studies have been performed to assess the effects of load carriage on humans. Factors studied included total load, load distribution, and various load carriage systems. Conditions range from forced marches of several days to balance, treadmill or circuit tests in the laboratory. Formal assessment methods are mostly based on physiological or biomechanical measurements or ratings of perceived exertion. The principal conclusions of the scientific literature are that biomechanical measures and subject perceptions are good indicators of certain design variations in load carriage systems, but have not been developed to full advantage. Generally, physiological measures are not sensitive enough to reflect subtle changes in configuration, although they provide very useful information on the effects of total load and environmental conditions. Also, the relationship between user perceived stress under load and quantitative measurements is not very well developed. That is, a quantifiable, repeatable measure of the ergonomic merit of a design is still an open area of research, which ERG is undertaking in this project.

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